# Section 6.0 Efficiencies of Best Management Practices

Determination of the efficiencies of Best Management Practices (BMP) is best performed using data that accurately represent water quality and pollution loading before, during, and after remining has occurred. Water quality and flow data that are used to determine baseline pollution loading for pre-existing discharges can be compared to data collected to monitor the same discharges after mining operations have been completed. Because the effects of both remining operations and associated BMPs are generally not immediate and can continue well beyond mine closure, it is important to consider water quality and flow conditions for a period of time (e.g., > 2 years) following site closure.

Site-specific efficiency statements for BMPs have been included in each section of this Guidance Manual. The purpose of this section is to: 1) present observed results of the effects of the implementation of 12 BMPs at over 100 remining sites in Pennsylvania using existing data, and 2) analyze these data, using statistical methods, in order to predict BMP efficiencies at remining sites throughout the Appalachian coal region. Efficiencies are presented for the following BMPs, as implemented individually or in combination:

**Regrading**: the restoration of positive drainage to pre-Surface Mining Control and Reclamation Act (SMCRA) surface mined areas. Regrading can be to approximate original contour (if adequate spoil is available) or terraced (if existing spoil is inadequate or if terracing will result in a higher land use).

**Revegetation**: the establishment of a diverse and permanent vegetative cover on inadequately vegetated pre-SMCRA surface-mined areas that is adequate to control surface-water infiltration and erosion.

**Daylighting**: the exposure by surface mining of a deep-mined coal seam, with the purpose of removal of the remaining coal.

**Special Handling of Acid-Producing Materials**: the selective placement of acid-generating overburden rock at a position within the backfill that is advantageous for reducing the amount of acid that would otherwise be generated from that rock.

**Alkaline Addition**: the importation of off-site calcareous material to a mine site. Alkaline addition is used in a variety of circumstances, particularly where a mine lacks sufficient naturally-occurring calcareous rock, but does contain a sufficient amount of pyritic material that could produce mine drainage pollution in the absence of neutralizers. Alkaline addition is measured as tons of $CaCO_3$ equivalent/acre.

**Water Handling Systems:** refers to any BMP that is specifically designed to: 1) reduce the amount of surface water that could infiltrate into the spoil and become ground water, or 2) channel ground water through spoil with the purpose of reducing water contact time with spoil and/or lowering the ground water table or preventing ground water from entering the spoil.

**Passive Treatment**: means of treating polluted mine drainage chemically and/or biologically such that metals concentrations are oxidized or reduced and acidity is neutralized. Compared with conventional chemical treatment (the typical alternative), passive methods generally require more surface area, but use less costly reagents, and require less operational attention, power, and maintenance.

**Coal Refuse Removal**: the elimination or reduction of abandoned coal waste piles. This material is typically sent to power plants for generation of electricity. In addition to the elimination or reduction of the size of the pile, the site of disturbance is regraded and revegetated.

**Biosolids Addition**: the application of nutrient-rich organic materials resulting from the treatment of sewage sludge (a solid, semi-solid or liquid residue generated during the treatment of domestic sewage in a treatment works) as a soil amendment for enhancement of plant growth on surface mines.

**Mining of Highly Alkaline Strata**: the encountering and mixing of naturally-occurring calcareous rock during the mining process. The mining plan may have to be adjusted to ensure that sufficient calcareous rock is encountered.

**Alkaline Redistribution**: the process of taking excess calcareous material from a portion of a mine and placing it in areas of the mine that lack calcareous materials. Typically, these areas lacking calcareous materials would not produce acceptable post-mining water quality without the addition of the calcareous material.

BMP efficiencies presented in this section are based on data provided by Pennsylvania Department of Environmental Protection (PA DEP) as a remining site study (PA Remining Site Study). The database from this study existed prior to the initiation of this evaluation, and includes summary water quality information and associated BMPs only. Therefore, factors that may have affected discharges in addition to the associated BMPs (such as compliance history) were not considered in this evaluation. The PA Remining Study was not specifically designed for the purposes of evaluating or determining the BMP efficiencies presented in this section. It is, however, the largest database available on completed remining sites and includes baseline data, post-mining data, and a record of BMPs used on 113 mine sites.

In spite of certain limitations of the data evaluated, these data include 231 discharges from 112 closed remining operations, and are the most comprehensive compiled to date regarding the efficiency of remining. These data are considered highly suited for the determination of BMP efficiencies, and the BMP efficiencies that have been predicted using these data can be considered the best available at this time. The advantages of this data set include:

- Over 100 different remining sites and over 230 pre-existing discharges are represented.
- Baseline data include monthly samples, typically for one year.
- Post-mining data include at least one year of monthly sample results.
- Post-mining data represent conditions following reclamation of remining sites.
- BMPs implemented are identified for each discharge.
- Water quality data represent ground-water discharges that are hydrologically connected to the mine.

## Limitations

It is important to note while reviewing this section that, although the data set used is the most extensive available on remining at this time, there are some limitations to its use for evaluating BMP efficiencies.

- The data is specific and exclusive to remining operations in the Pennsylvania bituminous coal regions. Although hydrologically and geologically very similar, remining in other parts of the Appalachian coalfields may exhibit slight differences.

- All permits were State-approved, Rahall remining permits and sites have been reclaimed to at least Stage II bond release standards. During permit application review, for operations thought to be potentially environmentally detrimental (i.e., resulting in increased pollution loadings), permits are either denied or amended to preclude degradation.

- This data set does not include non Rahall-type remining operations where pre-existing discharges are subject to statutory effluent limitations.

- No discharge data from mining on areas previously unmined, or discharge data from areas unaffected by BMPs (i.e., control data) were included.

- All sites all had at least monthly water quality analysis and flow measurement requirements for determining baseline, as well as during-mining and post-mining monitoring data. However, no compensation has been applied for sampling through periods of abnormal precipitation (well above or below the average).

- At this time, only contaminant loading and flow data are available. Review of concentration data would permit a more rigorous determination of BMP efficiency. Determination of whether a change in flow or contaminant concentration effected the change in load would permit determinations as to whether a specific BMP made a physical (flow) and/or geochemical (concentration) difference. These data may be available in the near future and an in-depth analysis and discussion may follow.

- For mines reclaimed only recently, the post-mining data may not be fully representative of equilibrium conditions. During this early period (~ 2 years), the water table is rebounding and discharge rates may be below those that will occur once the water table has reached equilibrium. Because the most recently collected 12 months of data (at the time of database compilation) was used in this study, most sites have been reclaimed for a number of years and the water table should have stabilized in the backfill.

## 6.1 Pennsylvania DEP - Remining Site Study

In 1998, Pennsylvania DEP evaluated water-quality and flow data for 248 pre-existing discharges from 112 remining sites that had been reclaimed to at least Stage II bond release standards (completely backfilled and revegetated). The remining sites were scattered throughout the bituminous coal region of the state and most heavily concentrated in the southwestern counties. The most recently available 12 months of pollution loading and flow data were compared against baseline loading and flow data (usually 12 months) for each pre-existing discharge. The same statistical test used to detect significant increases in pollution load (Tukey, 1976; PA DER, 1988) was used to determine whether there were significant decreases in pollution load. In addition, the current (or most recently available) median pollution load was calculated in order to quantify the actual increase or decrease in pollution load. This analysis was conducted for acidity, total iron, total manganese, and total aluminum loadings.

Results of the analysis for each individual discharge or discharges identified by and combined into hydrologically-connected units were entered into a database. The database also identified the best management practices employed during remining operations that were expected to have an impact on the water quality of that discharge. A single surface mining permit, more often than not, includes several individual discharges or hydrologic units and implements multiple BMPs. Some or all of the employed BMPs may be applicable to each discharge or hydrologic unit. Therefore, analysis of BMP effect on discharges was performed at the discharge or hydrologic-unit level, not at the permit level.

Of the 248 discharges included in the database, some could not be used for BMP efficiency analyses due to missing or unavailable information or data. Six monitoring points did not have baseline water quality data for any parameter, most likely due to an absence of flow. Ten other discharges did not have any associated BMP information. Therefore, the total number of discharges used in the BMP efficiency analyses was 231, from 109 permits.

Sulfate loadings and flow rates were also analyzed in this section to yield insight as to which BMPs may have caused the observed loadings changes. Sulfate loading trends may indicate if changes in loading rates of acidity, iron, manganese, and/or aluminum are due to geochemical changes in acid mine drainage (AMD) production (increases or decreases in pyrite oxidation). Sulfate ions are a conservative indicator of AMD production. Flow rate data may indicate whether changes to contaminant loadings are due to changes in the flow rate. These two parameters can in turn indicate if an improvement in water quality is related to a particular geochemically-based or physically-based BMP.

## 6.2 Observed Results

The database was used to summarize the number of discharges which showed statistically significant increases, decreases, or no change in pollution load and to compare the aggregate (combined) median pollution load. Statistical significance is determined by comparing the baseline upper and lower confidence limits about the median pollution load against the upper and lower confidence limits about the post-mining median. BMP effects on discharges were rated as follows:

- No significant difference - If the baseline and post-mining confidence intervals overlap, then there is no statistically significant difference and the median pollutant loading of the discharge is considered unchanged.

- Significantly degraded - If the post-mining lower confidence limit exceeds the baseline upper confidence limit, then there is a significant increase in median load.

- Significantly improved - If the post-mining upper confidence limit is lower than the baseline lower confidence limit, there is a significant decrease in median load.

- Eliminated - If the post-mining upper confidence limit was zero, the pollution load was considered to have been eliminated. This does not necessarily mean that the discharge was physically eliminated, only that with 95 percent confidence, the median pollution loads were zero.

This analysis was performed for each discharge affected by any of the 12 specific BMPs listed earlier in this section. The results of the observed BMP effects on pre-existing discharges are summarized by BMP and parameter in Table 6.2a.

Most discharges (or hydrologic units) were affected by multiple BMPs. For that reason, BMP effects on a single discharge may be represented in Table 6.2a under several different BMPs. For example, surface regrading, revegetation, and daylighting may have been implemented in an area affecting a single discharge. In Table 6.2a, the water quality results for that discharge would be represented in the summary results for each of these BMPs separately. Therefore, changes in pollution-loading rates may not be attributed solely to that BMP, but may have been affected by a group of BMPs. Table 6.2b summarizes the observed effects of BMPs on discharges by BMP group and parameter.

**Table 6.2a: Pennsylvania Remining Permits, Summary of Observed Water Quality Results by Individual BMP (Appendix B, Pennsylvania Remining Site Study)**

## Water Quality Results - Overall

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 43 | 19.1% |
| Significantly improved | 57 | 25.3% |
| No significant difference | 123 | 54.7% |
| Significantly degraded | 2 | 0.9% |
| Total for parameter | 225 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 32 | 20.6% |
| Significantly improved | 31 | 20.0% |
| No significant difference | 78 | 50.3% |
| Significantly degraded | 14 | 9.0% |
| Total for parameter | 155 | |

| Iron | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 49 | 23.7% |
| Significantly improved | 37 | 17.9% |
| No significant difference | 110 | 53.1% |
| Significantly degraded | 11 | 5.3% |
| Total for parameter | 207 | |

| Aluminum | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 21 | 17.9% |
| Significantly improved | 23 | 19.7% |
| No significant difference | 69 | 59.0% |
| Significantly degraded | 4 | 3.4% |
| Total for parameter | 117 | |

| Sulfate | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 43 | 18.7% |
| Significantly improved | 47 | 20.4% |
| No significant difference | 116 | 50.4% |
| Significantly degraded | 24 | 10.4% |
| Total for parameter | 230 | |

| Flow | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 42 | 18.2% |
| Significantly improved | 54 | 23.4% |
| No significant difference | 122 | 52.8% |
| Significantly degraded | 13 | 5.6% |
| Total for parameter | 231 | |

**Water Quality Results by BMP - Alkaline Addition > 100 tons/acre**

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 4 | 36.4% |
| Significantly improved | 3 | 27.3% |
| No significant difference | 3 | 27.3% |
| Significantly degraded | 1 | 9.1% |
| Total for parameter | 11 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 1 | 16.7% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 3 | 50.0% |
| Significantly degraded | 2 | 33.3% |
| Total for parameter | 6 | |

| Iron | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 5 | 45.5% |
| Significantly improved | 1 | 9.1% |
| No significant difference | 4 | 36.4% |
| Significantly degraded | 1 | 9.1% |
| Total for parameter | 11 | |

| Aluminum | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 1 | 100.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 1 | |

| Sulfate | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 5 | 45.5% |
| Significantly improved | 1 | 9.1% |
| No significant difference | 4 | 36.4% |
| Significantly degraded | 1 | 9.1% |
| Total for parameter | 11 | |

| Flow | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 4 | 36.4% |
| Significantly improved | 3 | 27.3% |
| No significant difference | 3 | 27.3% |
| Significantly degraded | 1 | 9.1% |
| Total for parameter | 11 | |

**Water Quality Results by BMP - Alkaline Addition < 100 tons/acre**

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 11 | 16.9% |
| Significantly improved | 11 | 16.9% |
| No significant difference | 43 | 66.2% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 65 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 8 | 20.5% |
| Significantly improved | 5 | 12.8% |
| No significant difference | 22 | 56.4% |
| Significantly degraded | 4 | 10.3% |
| Total for parameter | 39 | |

| Iron | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 13 | 21.7% |
| Significantly improved | 9 | 15.0% |
| No significant difference | 37 | 61.7% |
| Significantly degraded | 1 | 1.7% |
| Total for parameter | 60 | |

| Aluminum | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 5 | 19.2% |
| Significantly improved | 2 | 7.7% |
| No significant difference | 19 | 73.1% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 26 | |

| Sulfate | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 14 | 20.9% |
| Significantly improved | 11 | 16.4% |
| No significant difference | 36 | 53.7% |
| Significantly degraded | 6 | 9.0% |
| Total for parameter | 67 | |

| Flow | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 14 | 20.9% |
| Significantly improved | 9 | 13.4% |
| No significant difference | 41 | 61.2% |
| Significantly degraded | 3 | 4.5% |
| Total for parameter | 67 | |

## Water Quality Results by BMP - On-site Alkaline Redistribution

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 5 | 83.3% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 1 | 16.7% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 6 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 4 | 100.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 0 | 0.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 4 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 2 | 66.7% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 1 | 33.3% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 3 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 3 | 100.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 0 | 0.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 3 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 4 | 66.7% |
| Significantly improved | 1 | 16.7% |
| No significant difference | 1 | 16.7% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 6 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 4 | 66.7% |
| Significantly improved | 1 | 16.7% |
| No significant difference | 1 | 16.7% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 6 | |

## Water Quality Results by BMP - Biosolids application

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 5 | 83.3% |
| No significant difference | 1 | 16.7% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 6 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 3 | 60.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 2 | 40.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 5 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 3 | 50.0% |
| Significantly improved | 1 | 16.7% |
| No significant difference | 2 | 33.3% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 6 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 2 | 66.7% |
| Significantly improved | 1 | 33.3% |
| No significant difference | 0 | 0.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 3 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 2 | 33.3% |
| Significantly improved | 3 | 50.0% |
| No significant difference | 1 | 16.7% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 6 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 2 | 33.3% |
| Significantly improved | 3 | 50.0% |
| No significant difference | 1 | 16.7% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 6 | |

**Water Quality Results by BMP - Coal Refuse Removal**

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 2 | 22.2% |
| Significantly improved | 4 | 44.4% |
| No significant difference | 3 | 33.3% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 9 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 5 | 83.3% |
| Significantly degraded | 1 | 16.7% |
| Total for parameter | 6 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 2 | 28.6% |
| No significant difference | 4 | 57.1% |
| Significantly degraded | 1 | 14.3% |
| Total for parameter | 7 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 2 | 33.3% |
| No significant difference | 4 | 66.7% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 6 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 2 | 22.2% |
| No significant difference | 7 | 77.8% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 9 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 1 | 11.1% |
| No significant difference | 8 | 88.9% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 9 | |

**Water Quality Results by BMP - Construction of Special Water Handling Facilities**

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 5 | 22.7% |
| Significantly improved | 6 | 27.3% |
| No significant difference | 11 | 50.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 22 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 5 | 26.3% |
| Significantly improved | 4 | 21.1% |
| No significant difference | 8 | 42.1% |
| Significantly degraded | 2 | 10.5% |
| Total for parameter | 19 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 7 | 30.4% |
| Significantly improved | 4 | 17.4% |
| No significant difference | 11 | 47.8% |
| Significantly degraded | 1 | 4.3% |
| Total for parameter | 23 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 2 | 18.2% |
| Significantly improved | 1 | 9.1% |
| No significant difference | 8 | 72.7% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 11 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 6 | 26.1% |
| Significantly improved | 4 | 17.4% |
| No significant difference | 12 | 52.2% |
| Significantly degraded | 1 | 4.3% |
| Total for parameter | 23 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 6 | 26.1% |
| Significantly improved | 5 | 21.7% |
| No significant difference | 10 | 43.5% |
| Significantly degraded | 2 | 8.7% |
| Total for parameter | 23 | |

## Water Quality Results by BMP - Daylighting

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 28 | 17.1% |
| Significantly improved | 39 | 23.8% |
| No significant difference | 96 | 58.5% |
| Significantly degraded | 1 | 0.6% |
| Total for parameter | 164 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 21 | 19.4% |
| Significantly improved | 23 | 21.3% |
| No significant difference | 57 | 52.8% |
| Significantly degraded | 7 | 6.5% |
| Total for parameter | 108 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 27 | 17.3% |
| Significantly improved | 35 | 22.4% |
| No significant difference | 87 | 55.8% |
| Significantly degraded | 7 | 4.5% |
| Total for parameter | 156 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 17 | 18.5% |
| Significantly improved | 13 | 14.1% |
| No significant difference | 58 | 63.0% |
| Significantly degraded | 4 | 4.3% |
| Total for parameter | 92 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 28 | 16.6% |
| Significantly improved | 33 | 19.5% |
| No significant difference | 87 | 51.5% |
| Significantly degraded | 21 | 12.4% |
| Total for parameter | 169 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 28 | 16.5% |
| Significantly improved | 35 | 20.6% |
| No significant difference | 96 | 56.5% |
| Significantly degraded | 11 | 6.5% |
| Total for parameter | 170 | |

## Water Quality Results by BMP - Mining of highly alkaline strata

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 3 | 25.0% |
| Significantly improved | 5 | 41.7% |
| No significant difference | 4 | 33.3% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 12 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 2 | 50.0% |
| No significant difference | 2 | 50.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 4 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 3 | 23.1% |
| Significantly improved | 2 | 15.4% |
| No significant difference | 5 | 38.5% |
| Significantly degraded | 3 | 23.1% |
| Total for parameter | 13 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 3 | 100.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 3 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 2 | 15.4% |
| Significantly improved | 4 | 30.8% |
| No significant difference | 6 | 46.2% |
| Significantly degraded | 1 | 7.7% |
| Total for parameter | 13 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 2 | 15.4% |
| Significantly improved | 6 | 46.2% |
| No significant difference | 5 | 38.5% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 13 | |

**Water Quality Results by BMP - Passive Treatment System Construction**

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 1 | 100.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 1 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 1 | 100.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 0 | 0.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 1 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 1 | 50.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 1 | 50.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 2 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 0 | 0.0% |
| No significant difference | 1 | 100.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 1 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 1 | 50.0% |
| No significant difference | 1 | 50.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 2 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 0 | 0.0% |
| Significantly improved | 1 | 50.0% |
| No significant difference | 1 | 50.0% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 2 | |

**Water Quality Results by BMP - Special handling of acid-forming material**

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 11 | 14.1% |
| Significantly improved | 17 | 21.8% |
| No significant difference | 48 | 61.5% |
| Significantly degraded | 2 | 2.6% |
| Total for parameter | 78 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 12 | 23.5% |
| Significantly improved | 8 | 15.7% |
| No significant difference | 28 | 54.9% |
| Significantly degraded | 3 | 5.9% |
| Total for parameter | 51 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 11 | 15.7% |
| Significantly improved | 15 | 21.4% |
| No significant difference | 39 | 55.7% |
| Significantly degraded | 5 | 7.1% |
| Total for parameter | 70 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 6 | 15.8% |
| Significantly improved | 6 | 15.8% |
| No significant difference | 25 | 65.8% |
| Significantly degraded | 1 | 2.6% |
| Total for parameter | 38 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 11 | 13.8% |
| Significantly improved | 15 | 18.8% |
| No significant difference | 42 | 52.5% |
| Significantly degraded | 12 | 15.0% |
| Total for parameter | 80 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 11 | 13.8% |
| Significantly improved | 16 | 20.0% |
| No significant difference | 47 | 58.8% |
| Significantly degraded | 6 | 7.5% |
| Total for parameter | 80 | |

**Water Quality Results by BMP - Surface Regrading**

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 30 | 19.5% |
| Significantly improved | 41 | 26.6% |
| No significant difference | 82 | 53.2% |
| Significantly degraded | 1 | 0.6% |
| Total for parameter | 154 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 21 | 18.9% |
| Significantly improved | 23 | 20.7% |
| No significant difference | 58 | 52.3% |
| Significantly degraded | 9 | 8.1% |
| Total for parameter | 111 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 33 | 24.1% |
| Significantly improved | 25 | 18.2% |
| No significant difference | 72 | 52.6% |
| Significantly degraded | 7 | 5.1% |
| Total for parameter | 137 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 14 | 16.7% |
| Significantly improved | 17 | 20.2% |
| No significant difference | 51 | 60.7% |
| Significantly degraded | 2 | 2.4% |
| Total for parameter | 84 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 27 | 17.4% |
| Significantly improved | 32 | 20.6% |
| No significant difference | 81 | 52.3% |
| Significantly degraded | 15 | 9.7% |
| Total for parameter | 155 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 26 | 16.7% |
| Significantly improved | 42 | 26.9% |
| No significant difference | 78 | 50.0% |
| Significantly degraded | 10 | 6.4% |
| Total for parameter | 156 | |

**Water Quality Results by BMP - Surface Revegetation**

| Acidity | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 35 | 20.1% |
| Significantly improved | 46 | 26.4% |
| No significant difference | 93 | 53.4% |
| Significantly degraded | 0 | 0.0% |
| Total for parameter | 174 | |

| Manganese | # Discharges | Percent of Discharges |
|---|---|---|
| Discharge eliminated | 26 | 20.5% |
| Significantly improved | 25 | 19.7% |
| No significant difference | 67 | 52.8% |
| Significantly degraded | 9 | 7.1% |
| Total for parameter | 127 | |

| Iron | | |
|---|---|---|
| Discharge eliminated | 40 | 25.3% |
| Significantly improved | 29 | 18.4% |
| No significant difference | 82 | 51.9% |
| Significantly degraded | 7 | 4.4% |
| Total for parameter | 158 | |

| Aluminum | | |
|---|---|---|
| Discharge eliminated | 17 | 17.3% |
| Significantly improved | 20 | 20.4% |
| No significant difference | 58 | 59.2% |
| Significantly degraded | 3 | 3.1% |
| Total for parameter | 98 | |

| Sulfate | | |
|---|---|---|
| Discharge eliminated | 34 | 19.3% |
| Significantly improved | 40 | 22.7% |
| No significant difference | 85 | 48.3% |
| Significantly degraded | 17 | 9.7% |
| Total for parameter | 176 | |

| Flow | | |
|---|---|---|
| Discharge eliminated | 33 | 18.6% |
| Significantly improved | 46 | 26.0% |
| No significant difference | 88 | 49.7% |
| Significantly degraded | 10 | 5.7% |
| Total for parameter | 177 | |

Of the 12 BMPs assessed, only 3 were reported to be used singly, accounting for effects on 8.7 percent (20) of 231 discharges. The BMPs reported as being implemented singly were regrading (affecting 1 discharge), revegetation (affecting 5 discharges), and daylighting (affecting 14 discharges).  However, the possibility that regrading was implemented alone, without revegetation, is doubtful. The pollution abatement of the remaining discharges was affected by BMP groups containing up to 6 BMPs. Table 6.2b lists the observed effects of the various BMP groupings implemented on 231 pre-existing discharges or hydrologic units.

# Table 6.2b: PA Remining Study - Observed Effects of BMP Groupings on Discharges

**BMP Group Code**
(a) Regrading
(b) Revegetation
(c) Daylighting
(d) Special Handling
(e) Alkaline Addition < 100 tons/acre
(f) Special Water Handling Facilities
(g) Passive Treatment
(h) Coal Refuse Removal
(i) Biosolids Application
(j) Mining High Alkaline Strata
(k) Alkaline Addition > 100 tons/acre
(l) On-Site Alkaline Redistribution

**Ratings Code**
4 Eliminated
3 Improved
2 Unchanged
1 Got Worse

| | | | Rating | | | | | |
|---|---|---|---|---|---|---|---|---|
| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
| c | 14 | acidity | 0 | 9 | 3 | 1 | 30.8% | 0.0% |
| | | iron | 0 | 5 | 4 | 3 | 58.3% | 0.0% |
| | | manganese | 1 | 4 | 4 | 2 | 54.5% | 9.1% |
| | | aluminum | 1 | 5 | 2 | 2 | 40.0% | 10.0% |
| | | flow | 0 | 12 | 1 | 1 | 14.3% | 0.0% |
| | | sulfate | 2 | 8 | 3 | 1 | 28.6% | 14.3% |
| b | 5 | acidity | 0 | 3 | 2 | 0 | 40.0% | 0.0% |
| | | iron | 1 | 3 | 1 | 0 | 20.0% | 20.0% |
| | | manganese | 0 | 4 | 1 | 0 | 20.0% | 0.0% |
| | | aluminum | 0 | 2 | 3 | 0 | 60.0% | 0.0% |
| | | flow | 0 | 2 | 3 | 0 | 60.0% | 0.0% |
| | | sulfate | 1 | 1 | 3 | 0 | 60.0% | 20.0% |
| a | 1 | acidity | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | aluminum | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| c, l | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| c, h | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| c, e | 12 | acidity | 0 | 8 | 3 | 1 | 33.3% | 0.0% |
| | | iron | 0 | 8 | 2 | 1 | 27.3% | 0.0% |
| | | manganese | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 1 | 8 | 1 | 2 | 25.0% | 8.3% |
| | | sulfate | 0 | 9 | 1 | 2 | 25.0% | 0.0% |
| c, d | 5 | acidity | 1 | 4 | 0 | 0 | 0.0% | 20.0% |
| | | iron | 1 | 3 | 0 | 0 | 0.0% | 25.0% |
| | | manganese | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | aluminum | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 1 | 4 | 0 | 0 | 0.0% | 20.0% |
| | | sulfate | 3 | 2 | 0 | 0 | 0.0% | 60.0% |
| b, i | 1 | acidity | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | flow | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| b, c | 5 | acidity | 0 | 1 | 2 | 2 | 80.0% | 0.0% |
| | | iron | 0 | 1 | 2 | 2 | 80.0% | 0.0% |
| | | manganese | 0 | 2 | 1 | 2 | 60.0% | 0.0% |
| | | aluminum | 1 | 2 | 0 | 2 | 40.0% | 20.0% |
| | | flow | 0 | 1 | 2 | 2 | 80.0% | 0.0% |
| | | sulfate | 0 | 1 | 2 | 2 | 80.0% | 0.0% |
| a, b | 18 | acidity | 0 | 9 | 2 | 7 | 50.0% | 0.0% |
| | | iron | 0 | 6 | 2 | 2 | 40.0% | 0.0% |
| | | manganese | 2 | 4 | 2 | 3 | 45.5% | 18.2% |
| | | aluminum | 0 | 3 | 2 | 1 | 50.0% | 0.0% |
| | | flow | 0 | 6 | 5 | 7 | 66.7% | 0.0% |
| | | sulfate | 1 | 7 | 3 | 7 | 55.6% | 5.6% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| c, h, j | 1 | acidity | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| c, e, f | 1 | acidity | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | flow | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| c, d, k | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| c, d, j | 3 | acidity | 0 | 0 | 2 | 0 | 100.0% | 0.0% |
| | | iron | 2 | 1 | 0 | 0 | 0.0% | 66.7% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 2 | 0 | 66.7% | 0.0% |
| | | sulfate | 0 | 2 | 1 | 0 | 33.3% | 0.0% |
| c, d, e | 5 | acidity | 0 | 3 | 0 | 2 | 40.0% | 0.0% |
| | | iron | 0 | 3 | 0 | 2 | 40.0% | 0.0% |
| | | manganese | 0 | 3 | 0 | 2 | 40.0% | 0.0% |
| | | aluminum | 0 | 3 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 0 | 3 | 0 | 2 | 40.0% | 0.0% |
| | | sulfate | 2 | 1 | 0 | 2 | 40.0% | 40.0% |
| b, d, l | 1 | acidity | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 1 | 100.0% | 0.0% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| b, d, k | 1 | acidity | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | manganese | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| b, d, e | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| b, c, k | 1 | acidity | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| b, c, g | 1 | acidity | 0 | 0 | 0 | 0 | - | - |
| | | iron | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| b, c, f | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | aluminum | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | flow | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | sulfate | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| b, c, e | 4 | acidity | 0 | 2 | 0 | 2 | 50.0% | 0.0% |
| | | iron | 0 | 2 | 0 | 1 | 33.3% | 0.0% |
| | | manganese | 1 | 1 | 1 | 1 | 50.0% | 25.0% |
| | | aluminum | 0 | 2 | 0 | 1 | 33.3% | 0.0% |
| | | flow | 0 | 3 | 0 | 1 | 25.0% | 0.0% |
| | | sulfate | 0 | 3 | 0 | 1 | 25.0% | 0.0% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| b, c, d | 2 | acidity | 0 | 1 | 1 | 0 | 50.0% | 0.0% |
| | | iron | 0 | 1 | 1 | 0 | 50.0% | 0.0% |
| | | manganese | 0 | 2 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 0 | 1 | 1 | 0 | 50.0% | 0.0% |
| | | sulfate | 0 | 0 | 2 | 0 | 100.0% | 0.0% |
| a, d, k | 1 | acidity | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | iron | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | manganese | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| a, d, e | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| a, c, j | 2 | acidity | 0 | 1 | 1 | 0 | 50.0% | 0.0% |
| | | iron | 0 | 0 | 1 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 1 | 1 | 0 | 50.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 2 | 0 | 100.0% | 0.0% |
| | | sulfate | 0 | 1 | 1 | 0 | 50.0% | 0.0% |
| a, c, d | 1 | acidity | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 0 | - | - |
| | | manganese | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | flow | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| a, b, k | 2 | acidity | 0 | 0 | 0 | 2 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 2 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 1 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 2 | 100.0% | 0.0% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| a, b, h | 3 | acidity | 0 | 1 | 2 | 0 | 66.7% | 0.0% |
| | | iron | 1 | 1 | 0 | 0 | 0.0% | 50.0% |
| | | manganese | 1 | 1 | 0 | 0 | 0.0% | 50.0% |
| | | aluminum | 0 | 2 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 0 | 2 | 1 | 0 | 33.3% | 0.0% |
| | | sulfate | 0 | 2 | 1 | 0 | 33.3% | 0.0% |
| a, b, g | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| a, b, f | 4 | acidity | 0 | 0 | 3 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 2 | 2 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 2 | 2 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 2 | 1 | 75.0% | 0.0% |
| | | sulfate | 0 | 1 | 2 | 1 | 75.0% | 0.0% |
| a, b, e | 4 | acidity | 0 | 4 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 3 | 1 | 0 | 25.0% | 0.0% |
| | | manganese | 1 | 3 | 0 | 0 | 0.0% | 25.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 3 | 1 | 0 | 25.0% | 0.0% |
| | | sulfate | 0 | 4 | 0 | 0 | 0.0% | 0.0% |
| a, b, d | 4 | acidity | 0 | 2 | 2 | 0 | 50.0% | 0.0% |
| | | iron | 0 | 2 | 2 | 0 | 50.0% | 0.0% |
| | | manganese | 0 | 1 | 2 | 0 | 66.7% | 0.0% |
| | | aluminum | 0 | 1 | 2 | 0 | 66.7% | 0.0% |
| | | flow | 0 | 2 | 2 | 0 | 50.0% | 0.0% |
| | | sulfate | 0 | 4 | 0 | 0 | 0.0% | 0.0% |
| a, b, c | 37 | acidity | 0 | 20 | 10 | 6 | 44.4% | 0.0% |
| | | iron | 2 | 22 | 4 | 9 | 35.1% | 5.4% |
| | | manganese | 1 | 19 | 7 | 3 | 33.3% | 3.3% |
| | | aluminum | 1 | 12 | 7 | 4 | 45.8% | 4.2% |
| | | flow | 3 | 18 | 11 | 5 | 43.2% | 8.1% |
| | | sulfate | 3 | 19 | 9 | 5 | 38.9% | 8.3% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| c, e, f, j | 2 | acidity | 0 | 0 | 1 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 1 | 50.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 0 | 2 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 2 | 100.0% | 0.0% |
| c, d, e, f | 1 | acidity | 0 | 0 | 0 | 0 | - | - |
| | | iron | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| b, c, d, e | 5 | acidity | 0 | 5 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 4 | 0 | 1 | 20.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 3 | 0 | 2 | 40.0% | 0.0% |
| | | sulfate | 0 | 2 | 1 | 2 | 60.0% | 0.0% |
| a, c, i, k | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| a, b, i, k | 2 | acidity | 0 | 0 | 2 | 0 | 100.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 1 | 50.0% | 0.0% |
| | | manganese | 0 | 1 | 0 | 1 | 50.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 1 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 1 | 1 | 100.0% | 0.0% |
| a, b, e, f | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | manganese | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 1 | 0 | 100.0% | 0.0% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| a, b, d, l | 3 | acidity | 0 | 0 | 0 | 3 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 3 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 2 | 100.0% | 0.0% |
| | | flow | 0 | 0 | 1 | 2 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 1 | 2 | 100.0% | 0.0% |
| a, b, d, k | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| a, b, d, j | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| a, b, d, h | 3 | acidity | 0 | 1 | 1 | 1 | 66.7% | 0.0% |
| | | iron | 0 | 1 | 1 | 0 | 50.0% | 0.0% |
| | | manganese | 0 | 2 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 1 | 1 | 0 | 50.0% | 0.0% |
| | | flow | 0 | 3 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 3 | 0 | 0 | 0.0% | 0.0% |
| a, b, d, f | 1 | acidity | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | iron | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | sulfate | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| a, b, c, l | 1 | acidity | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 0 | - | - |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | flow | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 1 | 100.0% | 0.0% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| a, b, c, k | 1 | acidity | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| a, b, c, j | 1 | acidity | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | iron | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 0 | 0 | 0 | - | - |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 1 | 0 | 0 | 0 | 0.0% | 100.0% |
| a, b, c, i | 1 | acidity | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | manganese | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | aluminum | 0 | 0 | 0 | 1 | 100.0% | 0.0% |
| | | flow | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | sulfate | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| a, b, c, f | 4 | acidity | 0 | 1 | 2 | 1 | 75.0% | 0.0% |
| | | iron | 0 | 1 | 1 | 2 | 75.0% | 0.0% |
| | | manganese | 0 | 1 | 1 | 1 | 66.7% | 0.0% |
| | | aluminum | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 0 | 3 | 0 | 1 | 25.0% | 0.0% |
| | | sulfate | 0 | 3 | 0 | 1 | 25.0% | 0.0% |
| a, b, c, e | 14 | acidity | 0 | 8 | 3 | 2 | 38.5% | 0.0% |
| | | iron | 0 | 8 | 2 | 2 | 33.3% | 0.0% |
| | | manganese | 1 | 7 | 3 | 1 | 33.3% | 8.3% |
| | | aluminum | 0 | 9 | 1 | 1 | 18.2% | 0.0% |
| | | flow | 2 | 8 | 2 | 2 | 28.6% | 14.3% |
| | | sulfate | 3 | 7 | 2 | 2 | 28.6% | 21.4% |
| a, b, c, d | 18 | acidity | 0 | 11 | 7 | 0 | 38.9% | 0.0% |
| | | iron | 1 | 8 | 5 | 2 | 43.8% | 6.3% |
| | | manganese | 0 | 4 | 4 | 1 | 55.6% | 0.0% |
| | | aluminum | 1 | 9 | 2 | 0 | 16.7% | 8.3% |
| | | flow | 3 | 10 | 5 | 0 | 27.8% | 16.7% |
| | | sulfate | 5 | 9 | 4 | 0 | 22.2% | 27.8% |

| BMP Group | Discharges Affected | Parameter | 1 | 2 | 3 | 4 | Improved or Eliminated % | Got Worse % |
|---|---|---|---|---|---|---|---|---|
| a, b, c, e, j | 3 | acidity | 0 | 2 | 1 | 0 | 33.3% | 0.0% |
| | | iron | 0 | 2 | 0 | 1 | 33.3% | 0.0% |
| | | manganese | 0 | 0 | 0 | 0 | - | - |
| | | aluminum | 0 | 3 | 0 | 0 | 0.0% | 0.0% |
| | | flow | 0 | 2 | 1 | 0 | 33.3% | 0.0% |
| | | sulfate | 0 | 2 | 1 | 0 | 33.3% | 0.0% |
| a, b, c, d, f | 8 | acidity | 0 | 7 | 0 | 1 | 12.5% | 0.0% |
| | | iron | 0 | 7 | 0 | 1 | 12.5% | 0.0% |
| | | manganese | 0 | 7 | 0 | 1 | 12.5% | 0.0% |
| | | aluminum | 0 | 7 | 0 | 1 | 12.5% | 0.0% |
| | | flow | 0 | 6 | 1 | 1 | 25.0% | 0.0% |
| | | sulfate | 0 | 7 | 0 | 1 | 12.5% | 0.0% |
| a, b, c, d, e | 12 | acidity | 0 | 8 | 2 | 2 | 33.3% | 0.0% |
| | | iron | 0 | 4 | 2 | 3 | 55.6% | 0.0% |
| | | manganese | 0 | 4 | 0 | 3 | 42.9% | 0.0% |
| | | aluminum | 0 | 1 | 0 | 2 | 66.7% | 0.0% |
| | | flow | 0 | 8 | 2 | 2 | 33.3% | 0.0% |
| | | sulfate | 1 | 6 | 3 | 2 | 41.7% | 8.3% |
| a, b, d, e, h, i | 1 | acidity | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | iron | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | manganese | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | aluminum | 0 | 0 | 1 | 0 | 100.0% | 0.0% |
| | | flow | 0 | 1 | 0 | 0 | 0.0% | 0.0% |
| | | sulfate | 0 | 0 | 1 | 0 | 100.0% | 0.0% |

## 6.3 Predicted Efficiencies

The ratings of BMP effects presented in Table 6.2b were used to predict the effects that individual BMPs would have on pollution loadings of acidity, iron, manganese, aluminum and sulfate and on flow rates of pre-existing discharges.

### 6.3.1 Statistical Approach

Because the effect of BMPs on pollutant loadings in each discharge were summarized using a rating on a four point scale (got worse, no difference, improved, eliminated), the effects of the various BMPs on discharges were assessed statistically using a logit-link logistic regression model (Agresti, 1990). This model is based on the assumption that the natural logarithm of the odds of an event (in this case, that a discharge at least improves) is linearly related to certain predictor variables (in this case, 10-12 BMP variables, each indicating whether a specific BMP affected a discharge). The model can be used to predict the odds of an event's occurrence (i.e. the odds of a BMP improving or eliminating a discharge pollution load). In this way, the model can be used to evaluate the effect of each BMP separately, and make predictions of the likelihood of a discharge pollution load improving or being eliminated for a given BMP.

A number of assumptions were made while applying this model in order to predict BMP effects and determine BMP efficiencies. These assumptions include:

- The number of discharges that were observed to be significantly degraded by BMPs or BMP groups was so low that these discharges could not be used for meaningful statistical analyses. For example, the occurrences of "significantly degraded" in regards to acidity and aluminum loading were infrequent (occurred with acidity in 2 out of 225 discharges and occurred with aluminum in 4 out of 117 discharges). This is illustrative of how successful remining and the use of appropriate BMPs can be when properly implemented.

- It was assumed that both elimination and improvement of discharge pollution loadings are measures of success and could be combined into a single rating (i.e., "at least improved").

- The ratings of "no significant difference" and "significantly degraded" were not combined. Rahall permits stipulate that pollution loadings in pre-existing discharges must at least maintain baseline levels.

- The ratings "significantly improved" and "eliminated" were combined and assessed against "no significant difference." Therefore, the prediction variable had two possible outcomes (no difference or at least improved) and a logit model for a binary outcome was used.

- Summary data for the effects of passive treatment were only available for one discharge for acidity, manganese or aluminum. Summary data for alkaline addition greater than 100 tons/acre were only available for one discharge for aluminum. Therefore, passive treatment was not assessed in regards to acidity, manganese or aluminum, and alkaline addition greater than 100 tons/acre was not assessed in regards to aluminum.

- All discharges or hydrologic units were treated independently regardless of hydrologic connection or proximity to other discharges. It is probable that ratings for multiple discharges within the same permit would correlate more highly with each other than discharges from different permits. However, due to the wide range in numbers of discharges per permit (from one to ten), and the two-category nature of the outcome variable, a reliable estimate of this correlation could not be made.

### 6.3.2 Statistical Results

Model prediction results for individual BMP efficiencies in regards to acidity, iron, manganese, aluminum, sulfate, and flow, are reported in Tables 6.3a through 6.3f. Tables 6.3e and 6.3f present sulfate loadings and flow rate, respectively. As previously stated, sulfate and flow typically are not regulated, but but can provide insight into the causes of BMP effectiveness or ineffectiveness. The prediction results are indicated as follows:

> **Probability**: Out of 100 events, how frequently would discharges be improved with implementation of this BMP(s)
>
> **Ratio of Odds**: What are the odds of improvement if the BMP(s) is implemented vs. if the BMP(s) is not implemented (odds are the probability of at least improvement divided by the probability of no improvement). Due to the low number of discharges made significantly worse, this calculation does not include the possibility of degradation.
>
> **Odds Ratio for Interaction Terms**: Compares odds when both BMPs are implemented to odds when only one of the two BMPs is implemented.
>
> **Intercept term**: Estimated by separately assessing discharges both with and without each BMP, and extrapolating to the case where no BMPs are present. The intercept term estimates odds or probability of at least improvement when no BMPs are implemented.

#### 6.3.2.1 *Individual BMPs*

The first column of Tables 6.3a through 6.3f identifies the BMP assessed including the intercept term. The first row of of this column reports the intercept term that was used to predict odds ratios and probabilities, and reports the predicted probability of at least improvement given the situation where no BMPs are implemented. Because no discharges existed that were not affected by at least one BMP, the intercept was estimated by assessing the effect of the presence of each BMP individually, and extrapolating to the case where all those effects are absent.

The second column (Probability of at Least Improvement) of Tables 6.3a through 6.3f gives the model-predicted percentage of discharges that would be improved or eliminated in all discharges affected by that BMP. Since no data for discharges getting significantly worse were used, the percentages should be interpreted as the predicted percentage of discharges that would at least improve, as compared to those that would remain unchanged. The third column (Ratio of Odds) lists the ratio of odds of at least improvement where the given BMP is used with or without other BMPs compared with the odds of at least improvement where the BMP is not used. For example, a ratio of 2.0 indicates that the odds of at least improvement are two times higher when the BMP is used. Column 4 lists the number of discharges (n) that were affected by the particular BMP in regards to the parameter being assessed (i.e., acidity, iron, manganese, aluminum, sulfate, or flow).

<u>Statistical Significance</u>

Because some BMPs affected a small number of discharges, the odds ratios were reviewed for statistical significance. Column 5 lists the p-values calculated from the Wald Chi-square test for the statistical significance of odds ratios (i.e., that the corresponding odds ratio in Column 3 was significantly different from 1.0) tested at the 95 percent significance level (i.e., $\alpha = 0.05$) (Agresti, 1990). The value of $\alpha$ denotes the probability of a false positive, or the probability (based on the Wald test) that the model would determine that a BMP will have a significant effect on the odds of at least improvement, when in actuality the BMP does not have an effect. An odds ratio (from Column 3) significantly greater than one is an indication that inclusion of that BMP would significantly increase the odds of improvement. An odds ratio significantly less than one is an indication that inclusion of that BMP would significantly decrease the odds of improvement.

The p-values reported in Column 5 give the probability of observing (in a similar data set) an odds ratio equal to or greater than that in Column 3, if in truth that BMP does not have an effect on the odds of at least improvement. If the odds ratio in Column 3 is less than 1.0, the p-value gives the probability of observing an odds ratio equal to or less than the predicted odds ratio in Column 3. If the calculated p-value is less than the designated $\alpha$ (0.05), it can be concluded that the BMP has a significant effect on the odds of at least improvement at $\alpha = 0.05$. In other words, the $\alpha$ level of 0.05 indicates that with 95 percent confidence, the BMP has an effect on the discharge. For example, the calculated odds ratio for mining of high alkaline strata in regards to sulfate loading is 5.081 (based on 13 discharges that were affected). This means that, with 95 percent confidence, the odds of at least improvement are greater than 1.0 when mining of high alkaline strata is applied. This is an indication that the mining of high alkaline strata appears to have a significant positive effect on the chances of a discharge improving in regards to sulfate.

The last rows of Tables 6.3a through 6.3f (except for Table 6.3d) list significant interaction terms. These interaction terms state that the combined effect of the two BMPs is different from what would be expected given the sum of the predicted effects for those BMPs individually. For example, the significant interaction between special handling and water handling for acidity (Table 6.3a) shows that the odds of discharges at least improving are significantly less than would be expected given the combined positive effects of the two separate BMPs. Two odds ratios are listed for interaction terms in this table. Each term gives the odds ratio comparing the odds when both BMPs are present compared to the odds when only one of the two BMPs is present.

The presence of a significant interaction term alters the interpretation of the two BMP included in that interaction. For example, because there is a significant interaction between special handling and water handling for acidity (Table 6.3a), the odds ratio of 4.013 for water handling holds for all cases when water handling is implemented except when combined with special handling. Likewise, the odds ratio of 0.755 for special handling holds for all cases when special handling is implemented except when combined with water handling. In addition, the odds of at least improvement are 0.186 times higher (5.38 times lower) when water handling is used in conjunction with a BMP group that includes mining of high-alkaline strata than when a BMP group that includes special handling is used without water handling. Because the odds ratio for a

BMP present in a significant interaction does not apply in situations when the second BMP of the interaction is present, the test for significant interactions cannot lead to the conclusion that the BMP is significant in all cases, merely that it is significant when the second BMP is not present.

**Table 6.3a: PA Remining Study - Predicted Odds of Acidity Improvement or Elimination**

| BMP or BMP Group | Probability of at Least Improvement | Ratio of Odds with BMP(s) vs. Odds without BMP(s) | Discharges Affected (n) | p-value of Wald test (at $\alpha$=0.05) |
|---|---|---|---|---|
| None (Intercept term) | 37.3 | 1.00 | ---- | ---- |
| Regrading | 34.7 | 0.893 | 154 | 0.783 |
| Revegetation | 50.1 | 1.684 | 174 | 0.279 * |
| Daylighting | 37.1 | 0.991 | 164 | 0.981 |
| Special Handling | 31.0 | 0.755 | 78 | 0.387 * |
| Alkaline Addition <100 tons/acre | 25.4 | 0.570 | 65 | 0.098 |
| Water Handling | 71.4 | 4.182 | 22 | 0.040 * |
| Passive Treatment | Passive treatment affected only 1 discharge / discharge was unchanged | | | |
| Coal Refuse Removal | 57.6 | 2.283 | 9 | 0.285 |
| Biosolids Addition | 71.5 | 4.216 | 6 | 0.215 |
| Mining of Alk. Strata | 64.2 | 3.005 | 12 | 0.098 * |
| Alkaline Addition >100 tons/acre | 56.6 | 2.190 | 11 | 0.312 |
| Alkaline Redistribution | 80.9 | 7.127 | 6 | 0.083 |
| [1]Special Handling/ Water Handling | 7.7 | vs. Spec. Hand.: 0.186<br>vs. Water Hand.: 0.020 | 9 | 0.018 |

* Assessment of significance not meaningful due to presence in significant interaction term

Interaction terms: [1] Combined effect is less than expected from combining single effects

<u>2 discharges got worse</u>: These discharges were not used in statistical assessments of improvement or elimination of acidity. No predictions regarding discharges getting worse were made.

| <u>Discharge</u> | <u>BMPs Affecting Discharge</u> |
|---|---|
| 1 | Daylighting, Special Handling |
| 2 | Regrading, Special Handling, Alkaline Addition >100 tons/acre |

**Table 6.3b: PA Remining Study - Predicted Odds of Iron Improvement or Elimination**

| BMP or BMP Group | Probability of at Least Improvement | Ratio of Odds with BMP(s) vs. Odds without BMP(s) | Discharges Affected (n) | p-value of Wald test (at $\alpha$=0.05) |
|---|---|---|---|---|
| None (Intercept term) | 40.3 | 1.00 | ---- | ---- |
| Regrading | 36.0 | 0.831 | 137 | 0.657 |
| Revegetation | 51.3 | 1.559 | 158 | 0.359 |
| Daylighting | 37.7 | 0.896 | 156 | 0.775 |
| Special Handling | 42.1 | 1.075 | 70 | 0.833 * |
| Alk. Add.<100 tons/ac. | 32.2 | 0.703 | 60 | 0.311 |
| Water Handling | 73.1 | 4.013 | 23 | 0.049 * |
| Passive Treatment | 42.6 | 1.010 | 2 | 0.947 |
| Coal Refuse Removal | 26.2 | 0.525 | 7 | 0.492 |
| Biosolids Addition | 62.9 | 2.504 | 6 | 0.348 |
| Mining of Alk. Strata | 49.7 | 1.463 | 13 | 0.590 |
| Alk. Add. >100 tons/ac | 48.6 | 1.400 | 11 | 0.649 |
| Alkaline Redistribution | 61.3 | 2.340 | 3 | 0.505 |
| [1]Special Handling/<br>Water Handling | 18.3 | vs. Spec. Hand.: 0.308<br>vs. Water Hand.:0.083 | 10 | 0.021 |

* Assessment of significance not meaningful due to presence in significant interaction term
Interaction terms: [1]Combined effect is less than expected from combining single effects

<u>11 discharges got worse</u>: These discharges were not used in statistical assessments of improvement or elimination of iron. No predictions regarding discharges getting worse were made.

| Discharge | BMPs Affecting Discharge |
|---|---|
| 1 | Revegetation |
| 2 | Daylighting, Special Handling |
| 3-4 | Daylighting, Special Handling, Mining of High Alkaline Strata |
| 5 | Regrading, Special Handling, Alkaline Addition >100 tons/acre |
| 6 | Regrading, Revegetation, Coal Refuse Removal |
| 7-8 | Regrading, Revegetation, Daylighting |
| 9 | Regrading, Revegetation, Alkaline Addition <100 tons/acre, Water Handling |
| 10 | Regrading, Revegetation, Daylighting, Mining of High Alkaline Strata |
| 11 | Regrading, Revegetation, Daylighting, Special Handling |

**Table 6.3c: PA Study - Predicted Odds of Manganese Improvement or Elimination**

| BMP or BMP Group | Probability of at Least Improvement | Ratio of Odds with BMP(s) vs. Odds without BMP(s) | Discharges Affected (n) | p-value of Wald test (at $\alpha$=.05) |
|---|---|---|---|---|
| None (Intercept term) | 54.0 | 1.00 | ---- | ---- |
| Regrading | 50.0 | 0.850 | 111 | 0.717 * |
| Revegetation | 44.6 | 0.685 | 127 | 0.493 |
| Daylighting | 55.1 | 1.043 | 108 | 0.923 * |
| Special Handling | 60.3 | 1.290 | 51 | 0.534 |
| Alk. Add.<100 ton/ac | 42.3 | 0.624 | 39 | 0.250 |
| Water Handling | 90.4 | 8.010 | 19 | 0.024 |
| Passive Treatment | Passive treatment affected only 1 discharge/discharge was eliminated | | | |
| Coal Refuse Removal | 2.8 | 0.024 | 6 | 0.047 |
| Biosolids Addition | 96.1 | 21.150 | 5 | 0.060 |
| Mining of Alk. Strata | 68.8 | 1.877 | 4 | 0.551 |
| Alk.Add>100ton/ac | 6.2 | 0.056 | 6 | 0.098 |
| Alkaline Redistribution | 92.6 | 10.597 | 4 | 0.130 |
| [1]Special Handling/ Water Handling | 39.5 | vs. Special Handling: 0.43<br>vs. Water Handling: 0.069 | 9 | 0.016 |

* Assessment of significance not meaningful due to presence in significant interaction term
Interaction terms: [1]Combined effect is less than expected from combining single effects
<u>14 discharges got worse</u>: These discharges were not used in statistical assessments of improvement or elimination of manganese. No predictions regarding discharges getting worse were made.

| Discharges | BMPs Affecting Discharge |
|---|---|
| 1 | Daylighting |
| 2 | Regrading |
| 3 | Daylighting, Special Handling |
| 4, 5 | Regrading, Revegetation |
| 6 | Daylighting, Special Handling, Alkaline Addition >100 tons/acre |
| 7 | Revegetation, Daylighting, Water Handling |
| 8 | Revegetation, Daylighting, Alkaline Addition <100 tons/acre |
| 9 | Regrading, Special Handling, Alkaline Addition >100 tons/acre |
| 10 | Regrading, Revegetation, Coal Refuse Removal |
| 11 | Regrading, Revegetation, Alkaline Addition <100 tons/acre |
| 12 | Regrading, Revegetation, Daylighting |
| 13 | Regrading, Revegetation, Alkaline Addition <100 tons/acre, Water Handling |
| 14 | Regrading, Revegetation, Daylighting, Alkaline Addition <100 tons/acre |

**Table 6.3d: PA Remining Study - Predicted Odds of Aluminum Improvement or Elimination**

| BMP or BMP Group | Probability of at Least Improvement | Ratio of Odds with BMP(s) vs. Odds without BMP(s) | Discharges Affected (n) | p-value of Wald test (at $\alpha$=0.05) |
|---|---|---|---|---|
| None (Intercept term) | 59.1 | 1.00 | ---- | ---- |
| Regrading | 61.2 | 1.094 | 84 | 0.862 |
| Revegetation | 55.0 | 0.847 | 98 | 0.784 |
| Daylighting | 43.0 | 0.522 | 92 | 0.198 |
| Special Handling | 47.5 | 0.625 | 38 | 0.278 |
| Alkaline Addition <100 tons/acre | 49.9 | 0.690 | 26 | 0.446 |
| Water Handling | 59.5 | 1.017 | 11 | 0.980 |
| Passive Treatment | Passive treatment affected only 1 discharge/discharge was unchanged | | | |
| Coal Refuse Removal | 34.0 | 0.356 | 6 | 0.257 |
| Biosolids Addition | 96.4 | 18.587 | 3 | 0.074 |
| Mining of Alk. Strata | 26.1 | 0.245 | 3 | 0.372 |
| Alkaline Addition >100 tons/acre | Alkaline addition >100 affected only 1 discharge/discharge was unchanged | | | |
| Alkaline Redistribution | 93.3 | 9.711 | 3 | 0.139 |

4 discharges got worse: These discharges were not used in statistical assessments of improvement or elimination of aluminum. No predictions regarding discharges getting worse were made.

| Discharges | BMPs Affecting Discharge |
|---|---|
| 1 | Daylighting |
| 2 | Revegetation, Daylighting |
| 3 | Regrading, Revegetation, Daylighting |
| 4 | Regrading, Revegetation, Daylighting, Special Handling |

**Table 6.3e: PA Remining Study - Predicted Odds of Sulfate Improvement or Elimination**

| BMP or BMP Group | Probability of at Least Improvement | Ratio of Odds with BMP(s) vs. Odds without BMP(s) | Discharges Affected (n) | p-value of Wald test (at $\alpha$=0.05) |
|---|---|---|---|---|
| None (Intercept term) | 27.1 | 1.00 | ---- | ---- |
| Regrading | 12.3 | 0.377 | 155 | 0.030 |
| Revegetation | 75.1 | 8.113 | 176 | 0.002 * |
| Daylighting | 24.1 | 0.852 | 169 | 0.678 |
| Special Handling | 10.8 | 0.326 | 80 | 0.010 * |
| Alk. Add.<100 tons/ac | 38.9 | 1.708 | 67 | 0.457 * |
| Water Handling | 31.8 | 1.251 | 23 | 0.660 |
| Passive Treatment | 17.9 | 0.585 | 2 | 0.716 |
| Coal Refuse Removal | 9.0 | 0.267 | 9 | 0.167 |
| Biosolids Addition | 76.0 | 8.492 | 6 | 0.106 |
| Mining of Alk. Strata | 65.4 | 5.081 | 13 | 0.022 |
| Alk. Add.>100 tons/ac | 37.0 | 1.579 | 11 | 0.599 |
| Alkaline Redistribution | 80.1 | 10.794 | 6 | 0.041 |
| [1] Revegetation/ Alk. Add.<100 tons/ac | 44.8 | vs. Revegetation: 0.269<br>vs. Alk. Add.: 1.277 | 45 | 0.029 |
| [2]Special Handling/ Alk. Add.<100 tons/ac | 63.4 | vs. Spec. Hand.: 14.275<br>vs. Alk. Add.: 2.721 | 26 | 0.004 |

* Assessment of significance not meaningful due to presence in significant interaction term.
Interaction terms: [1]Combined effect is less than expected from combining single effects.
[2]Combined effect is more than expected from combining single effects .

<u>24 discharges got worse</u>: These discharges were not used in statistical assessments of improvement or elimination of sulfate. No predictions regarding discharges getting worse were made.

| <u>Discharges</u> | <u>BMPs Affecting Discharge</u> |
|---|---|
| 1, 2 | Daylighting |
| 3, 4, 5 | Daylighting, Special Handling |
| 6, 7 | Daylighting, Special Handling, Alkaline Addition <100 tons/acre |
| 8 | Revegetation |
| 9 | Revegetation, Daylighting, Water Handling |
| 10 | Regrading, Revegetation |
| 11 | Regrading, Revegetation, Special Handling, Alkaline Addition >100 tons/acre |
| 12-14 | Regrading, Revegetation, Daylighting |
| 15 | Regrading, Revegetation, Daylighting, Mining of High Alkaline Strata |
| 16-18 | Regrading, Revegetation, Daylighting, Alkaline Addition <100 tons/acre |
| 19-23 | Regrading, Revegetation, Daylighting, Special Handling |
| 24 | Regrading, Revegetation, Daylighting, Special Handling, Alk. Add. < 100 tons/acre |

**Table 6.3f: PA Remining Study - Predicted Odds of Flow Improvement or Elimination**

| BMP or BMP Group | Probability of at Least Improvement | Ratio of Odds with BMP(s) vs. Odds without BMP(s) | Discharges Affected (n) | p-value of Wald test (at $\alpha$=.05) |
|---|---|---|---|---|
| None (Intercept term) | 19.5 | 1.00 | ---- | ---- |
| Regrading | 16.4 | 0.807 | 156 | 0.621 |
| Revegetation | 66.0 | 8.009 | 177 | 0.005 * |
| Daylighting | 13.3 | 0.631 | 170 | 0.212 |
| Special Handling | 12.7 | 0.601 | 80 | 0.121 |
| Alk.Add.<100 ton/ac | 52.3 | 4.529 | 67 | 0.054 * |
| Water Handling | 21.3 | 1.118 | 23 | 0.827 |
| Passive Treatment | 14.9 | 0.721 | 2 | 0.821 |
| Coal Refuse Removal | 1.4 | 0.061 | 9 | 0.025 |
| Biosolids Addition | 80.4 | 16.897 | 6 | 0.072 |
| Mining of Alk. Strata | 88.7 | 32.367 | 13 | 0.002 * |
| Alkaline Addition >100 tons/acre | 30.4 | 1.798 | 11 | 0.489 |
| Alk. Redistribution | 66.3 | 8.109 | 6 | 0.082 * |
| [1]Revegetation/ Alk.Add.100tons/ac | 50.7 | vs. Revegetation: 0.529<br>vs. Alk. Addition: 0.935 | 45 | 0.014 |
| [1] Revegetation/ Mining of Alk. Strata | 65.8 | vs. Revegetation: 0.989<br>vs. Mining Alk.Strata: 0.245 | 12 | 0.019 |

* Assessment of significance not meaningful due to presence in significant interaction term.
Interaction terms: [1]Combined effect is less than expected from combining single effects.
<u>13 discharges got worse</u>: These discharges were not used in statistical assessments of improvement or elimination of sulfate. No predictions regarding discharges getting worse were made.

| Discharges | BMPs Affecting Discharge |
|---|---|
| 1 | Daylighting, Alkaline Addition < 100 tons/acre |
| 2 | Daylighting, Special Handling |
| 3 | Revegetation, Daylighting, Water Handling |
| 4 | Regrading, Special Handling, Alkaline Addition > 100 tons/acre |
| 5 | Regrading, Revegetation, Special Handling, Water Handling |
| 6, 7, 8 | Regrading, Revegetation, Daylighting |
| 9, 10 | Regrading, Revegetation, Daylighting, Alkaline Addition <100 tons/acre |
| 11-13 | Regrading, Revegetation, Daylighting, Special Handling |

#### 6.3.2.2 *BMP Combinations*

Selection of BMP combinations that are regularly employed during remining operations allows for a true determination of the efficiencies, rather than projected efficiencies for BMP combinations not presently occurring in the real world. BMP groups were selected for evaluation based on the observed implementation of the combinations in the Pennsylvania Remining Study. A secondary BMP group selection criterion was that each group affected a minimum of four discharges that were not significantly degraded. With under four discharges impacted by a BMP combination, the data subset is too small to allow credible conclusions and predictions based on the results. This selection of BMP combinations affecting four or more discharges allows study of the most frequently used combinations, by default.

The BMP groups of: (1) regrading and revegetation, (2) daylighting, and (3) regrading, revegetation, and daylighting were employed as control (reference) groups for comparison with groups containing additional BMPs. These three reference groups were selected for control because they are implemented as part of remining and occur as stand-alone BMPs. An operation would not be considered to be a remining operation unless one or more of these BMPs is conducted or coal refuse reprocessing is performed. These three BMP reference groups are directly related to the re-affecting of previously mined areas, because regrading and revegetation are used at abandoned surface-mined lands and daylighting is used for abandoned underground mines. Coal refuse reprocessing is seldom conducted (affected 9 out of 231 total discharges in the data set) and therefore was excluded as a control BMP.

This BMP group selection precluded the determination of potential efficacy of some BMP groups that, based on experience, may be highly successful in reducing pollution loads. Some BMPs, including mining into alkaline strata and alkaline addition (>100 tons per acre), are used infrequently, but have been shown to be quite successful when implemented.

The observed results were used to compare the three reference groupings to the selected BMP combinations. Performances of selected BMP combinations were compared to BMP reference groups using the observed study results (number of discharges eliminated, improved or unchanged) presented in Table 6.2b. This comparison provides an indication of relative observed performance, and does not necessarily predict BMP group efficiencies. Each reference group was compared to only those BMP groups that included the reference group (although groups did not need to include revegetation when compared to the reference group containing regrading and revegetation). Again, only those BMP groups that affected at least four non-worsening discharges were used in the calculation.

**Observed Percent Improved**: For each group, the percent of discharges that at least improved was determined by dividing the number of discharges that were improved or eliminated, by the number that were improved, eliminated, or did not significantly change (significantly degraded discharges were not included in the calculations because of their small number) and multiplying by 100.

**Observed Odds of Improvement**: For each group, the odds of at least improvement were calculated as the number of improved or eliminated discharges affected, divided by the number of discharges that did not significantly change.

**Observed Odds Ratio Compared to Reference**: The odds ratio for a given group represents the odds of at least improvement for that group, divided by the odds of at least improvement for the reference group.

**Percent Improved minus Reference Percent Improved**: The last column in Tables 6.3g through 6.3x gives the difference between the percentage of discharges affected by the BMP group that at least improved minus the percentage of discharges at least improved by the reference group.

For example, in Table 6.3m, Daylighting (reference group) improved or eliminated acidity loading in 4 discharges, and did not change acidity loading in 9 other discharges. Therefore, the observed percentage of discharges that at least improved is 4/13 x 100 = 30.8 percent, and the observed odds of at least improvement is 4/9 = 0.444. The group of Daylighting and Alkaline Addition <100 tons/acre affected 4 discharges that were improved or eliminated, and affected 8 discharges that did not significantly change. Therefore, the observed percentage of discharges that at least improved is 4/12 x 100 = 33.3 percent, and the observed odds of at least improvement was 4/8 = 0.500. The odds ratio comparing Daylighting and Alkaline Addition <100 tons/acre to the reference group (Daylighting) is 0.500/0.444 = 1.125. According to the observed data, the odds of at least improvement is 1.125 times higher when Daylighting and Alkaline Addition <100 tons/acre were used compared to when Daylighting was used alone.

For some BMP groups (i.e., Regrading, Revegetation, and Water Handling for acidity and iron), all discharges affected were improved or eliminated. This yields infinite odds, since the number of discharges improved or eliminated is divided by 0. Therefore, an odds ratio cannot be calculated for these groups.

**Table 6.3g: Analysis of Discrete Groups based on Observed Acidity Results Using Regrading and Revegetation as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation **(Reference)** | 18 | 9 | 9 | 50.0 | --- | --- |
| Regrading, Revegetation, Daylighting | 36 | 16 | 20 | 44.4 | 0.800 | -5.6 |
| Regrading, Revegetation, Special Handling | 4 | 2 | 2 | 50.0 | 1.000 | 0.0 |
| Regrading, Revegetation, Alkaline Addition <100 | 4 | 0 | 4 | 0.0 | 0.0 | -50.0 |
| Regrading, Revegetation, Water Handling | 4 | 4 | 0 | 100.0 | ∞ * | 50.0 |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 7 | 11 | 38.9 | 0.636 | -11.1 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 13 | 5 | 8 | 38.5 | 0.625 | -11.5 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 0.500 | -16.7 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.143 | -37.5 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

* Because all discharges for this grouping were improved, the odds of improvement would be 4 divided by 0. Therefore, the odds ratio is infinite.

**Table 6.3h: Analysis of Discrete Groups based on Observed Iron Results Using Regrading and Revegetation as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation **(Reference)** | 12 | 6 | 6 | 50.0 | --- | --- |
| Regrading, Revegetation, Daylighting | 37 | 13 | 22 | 37.1 | 0.591 | -12.9 |
| Regrading, Revegetation, Special Handling | 4 | 2 | 2 | 50.0 | 1.000 | 0.0 |
| Regrading, Revegetation, Alkaline Addition <100 | 4 | 1 | 3 | 25.0 | 0.333 | -25.0 |
| Regrading, Revegetation, Water Handling | 4 | 4 | 0 | 100.0 | ∞ * | 50.0 |
| Regrading, Revegetation, Daylighting, Special Handling | 16 | 7 | 8 | 46.7 | 0.875 | 3.3 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 0.500 | -16.7 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 9 | 5 | 4 | 55.6 | 1.250 | 5.6 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.143 | -37.5 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

* Because all discharges for this grouping were improved, the odds of improvement would be 5 divided by 0. Therefore, the odds ratio is infinite.

**Table 6.3i: Analysis of Discrete Groups based on Observed Manganese Results Using Regrading and Revegetation as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation **(Reference)** | 11 | 5 | 4 | 55.6 | --- | --- |
| Regrading, Revegetation, Daylighting | 30 | 10 | 19 | 34.5 | 0.421 | -21.1 |
| Regrading, Revegetation, Alkaline Addition <100 | 4 | 0 | 3 | 0.0 | 0.0 | -55.6 |
| Regrading, Revegetation, Water Handling | 4 | 4 | 0 | 100.0 | ∞ * | 44.4 |
| Regrading, Revegetation, Daylighting, Special Handling | 9 | 5 | 4 | 55.6 | 1.000 | -0.0 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 12 | 4 | 7 | 36.4 | 0.457 | -19.2 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 7 | 3 | 4 | 42.9 | 0.600 | -12.7 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.114 | -43.1 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

* Because all discharges for this grouping were improved, the odds of improvement would be 5 divided by 0. Therefore, the odds ratio is infinite.

**Table 6.3j: Analysis of Discrete Groups based on Observed Aluminum Results Using Regrading and Revegetation as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation **(Reference)** | 6 | 3 | 3 | 50.0 | --- | --- |
| Regrading, Revegetation, Daylighting | 24 | 11 | 12 | 47.8 | 0.917 | -2.2 |
| Regrading, Revegetation, Daylighting, Special Handling | 12 | 2 | 9 | 18.2 | 0.222 | -31.8 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 11 | 2 | 9 | 18.2 | 0.222 | -31.8 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.143 | -37.5 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

**Table 6.3k: Analysis of Discrete Groups based on Observed Sulfate Results Using Regrading and Revegetation as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation **(Reference)** | 18 | 10 | 7 | 58.8 | --- | --- |
| Regrading, Revegetation, Daylighting | 36 | 14 | 19 | 42.4 | 0.516 | -16.4 |
| Regrading, Revegetation, Special Handling | 4 | 0 | 4 | 0.0 | 0.000 | -58.8 |
| Regrading, Revegetation, Alkaline Addition <100 | 4 | 0 | 4 | 0.0 | 0.000 | -58.8 |
| Regrading, Revegetation, Water Handling | 4 | 3 | 1 | 75.0 | 2.099 | 16.2 |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 4 | 9 | 30.8 | 0.311 | -28.0 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 14 | 4 | 7 | 36.4 | 0.400 | -22.4 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 5 | 6 | 45.5 | 0.583 | -13.3 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.100 | -46.3 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

**Table 6.3l: Analysis of Discrete Groups based on Observed Flow Results Using Regrading and Revegetation as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation **(Reference)** | 18 | 12 | 6 | 66.7 | --- | --- |
| Regrading, Revegetation, Daylighting | 37 | 16 | 18 | 47.1 | 0.444 | -19.6 |
| Regrading, Revegetation, Special Handling | 4 | 2 | 2 | 50.0 | 0.500 | -16.7 |
| Regrading, Revegetation, Alkaline Addition <100 | 4 | 1 | 3 | 25.0 | 0.167 | -41.7 |
| Regrading, Revegetation, Water Handling | 4 | 3 | 1 | 75.0 | 1.500 | 8.3 |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 5 | 10 | 33.3 | 0.250 | -33.3 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 14 | 4 | 8 | 33.3 | 0.250 | -33.3 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 0.250 | -33.3 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 2 | 6 | 25.0 | 0.167 | -41.7 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

**Table 6.3m: Analysis of Discrete Groups based on Observed Acidity Results Using Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Daylighting **(Reference)** | 13 | 4 | 9 | 30.8 | --- | --- |
| Daylighting, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 1.125 | -2.5 |
| Regrading, Revegetation, Daylighting | 36 | 16 | 20 | 44.4 | 1.800 | 13.6 |
| Daylighting, Special Handling, Alkaline Addition <100 | 5 | 2 | 3 | 40.0 | 1.500 | 9.2 |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 7 | 11 | 38.9 | 1.432 | 8.1 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 13 | 5 | 8 | 38.5 | 1.406 | 7.7 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 1.125 | 2.5 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.321 | -18.3 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

* Because all discharges for this grouping were improved, the odds of improvement would be 4 divided by 0. Therefore, the odds ratio is infinite.

**Table 6.3n: Analysis of Discrete Groups based on Observed Iron Results Using Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Daylighting **(Reference)** | 12 | 7 | 5 | 58.3 | --- | --- |
| Daylighting, Alkaline Addition <100 | 11 | 3 | 8 | 27.3 | 0.268 | -31.0 |
| Regrading, Revegetation, Daylighting | 37 | 13 | 22 | 37.1 | 0.422 | -21.2 |
| Daylighting, Special Handling, Alkaline Addition <100 | 5 | 2 | 3 | 40.0 | 0.476 | -18.3 |
| Regrading, Revegetation, Daylighting, Special Handling | 16 | 7 | 8 | 46.7 | 0.625 | -11.6 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 0.357 | -25.0 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 9 | 5 | 4 | 55.6 | 0.893 | -2.7 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.102 | -45.8 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

**Table 6.3o: Analysis of Discrete Groups based on Observed Manganese Results Using Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Daylighting **(Reference)** | 11 | 6 | 4 | 60.0 | --- | --- |
| Regrading, Revegetation, Daylighting | 30 | 10 | 19 | 34.5 | 0.351 | -25.5 |
| Daylighting, Special Handling, Alkaline Addition <100 | 5 | 2 | 3 | 40.0 | 0.444 | -20.0 |
| Regrading, Revegetation, Daylighting, Special Handling | 9 | 5 | 4 | 55.6 | 0.833 | -4.4 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 12 | 4 | 7 | 36.4 | 0.381 | -23.6 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 7 | 3 | 4 | 42.9 | 0.500 | -17.1 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.095 | –47.5 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

**Table 6.3p: Analysis of Discrete Groups based on Observed Aluminum Results Using Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Daylighting **(Reference)** | 10 | 4 | 5 | 44.4 | --- | --- |
| Regrading, Revegetation, Daylighting | 24 | 11 | 12 | 47.8 | 1.146 | 3.4 |
| Regrading, Revegetation, Daylighting, Special Handling | 12 | 2 | 9 | 18.2 | 0.278 | -26.2 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 11 | 2 | 9 | 18.2 | 0.278 | -26.2 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.179 | –31.9 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

**Table 6.3q: Analysis of Discrete Groups based on Observed Sulfate Results Using Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Daylighting **(Reference)** | 14 | 4 | 8 | 33.3 | --- | --- |
| Daylighting, Alkaline Addition <100 | 12 | 3 | 9 | 25.0 | 0.666 | -8.3 |
| Regrading, Revegetation, Daylighting | 36 | 14 | 19 | 42.4 | 0.516 | 9.1 |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 4 | 9 | 30.8 | 0.889 | -2.5 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 14 | 4 | 7 | 36.4 | 1.143 | 3.1 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 5 | 6 | 45.5 | 1.667 | 12.2 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.286 | -20.8 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

**Table 6.3r: Analysis of Discrete Groups based on Observed Flow Results Using Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Daylighting **(Reference)** | 14 | 2 | 12 | 14.3 | --- | --- |
| Daylighting, Alkaline Addition <100 | 12 | 3 | 9 | 25.0 | 2.000 | 10.7 |
| Regrading, Revegetation, Daylighting | 37 | 16 | 18 | 47.1 | 5.333 | 32.8 |
| Daylighting, Special Handling, Alkaline Addition <100 | 5 | 2 | 3 | 40.0 | 4.000 | 25.7 |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 5 | 10 | 33.3 | 3.000 | 19.0 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 14 | 4 | 8 | 33.3 | 3.000 | 19.0 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 3.000 | 19.0 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 2 | 6 | 25.0 | 2.000 | 10.7 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

**Table 6.3s: Analysis of Discrete Groups based on Observed Acidity Results Using Regrading, Revegetation, and Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation, Daylighting **(Reference)** | 36 | 16 | 20 | 44.4 | — | --- |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 7 | 11 | 38.9 | 0.795 | -5.5 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 13 | 5 | 8 | 38.5 | 0.781 | -5.9 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 0.625 | -11.1 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.179 | -31.9 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

**Table 6.3t: Analysis of Discrete Groups based on Observed Iron Results Using Regrading, Revegetation, and Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation, Daylighting **(Reference)** | 37 | 13 | 22 | 37.1 | --- | --- |
| Regrading, Revegetation, Daylighting, Special Handling | 16 | 7 | 8 | 46.7 | 1.481 | 9.6 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 0.846 | -3.8 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 9 | 5 | 4 | 55.6 | 2.115 | 18.5 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.242 | -24.6 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

**Table 6.3u: Analysis of Discrete Groups based on Observed Manganese Results Using Regrading, Revegetation and Daylighting as a Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation, Daylighting **(Reference)** | 30 | 10 | 19 | 34.5 | --- | --- |
| Regrading, Revegetation, Daylighting, Special Handling | 9 | 5 | 4 | 55.6 | 2.376 | 21.1 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 12 | 4 | 7 | 36.4 | 1.086 | 1.9 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 7 | 3 | 4 | 42.9 | 1.426 | 8.4 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.272 | -22.0 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

**Table 6.3v: Analysis of Discrete Groups based on Observed Aluminum Results Using Regrading, Revegetation and Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation, Daylighting **(Reference)** | 24 | 11 | 12 | 47.8 | --- | --- |
| Regrading, Revegetation, Daylighting, Special Handling | 12 | 2 | 9 | 18.2 | 0.242 | -29.6 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 11 | 2 | 9 | 18.2 | 0.242 | -29.6 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.156 | -35.3 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

**Table 6.3w: Analysis of Discrete Groups based on Observed Sulfate Results Using Regrading, Revegetation, and Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation, Daylighting **(Reference)** | 36 | 14 | 19 | 42.4 | --- | --- |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 4 | 9 | 30.8 | 0.603 | -11.6 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 14 | 4 | 7 | 36.4 | 0.775 | -6.0 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 5 | 6 | 45.5 | 1.131 | 3.1 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 1 | 7 | 12.5 | 0.194 | -29.9 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

**Table 6.3x: Analysis of Discrete Groups based on Observed Flow Results Using Regrading, Revegetation, and Daylighting as Reference Group**

| BMP Group | Number of Discharges Affected | Number of Discharges Improved or Eliminated | Number of Discharges Unchanged | Observed Percent Improved | Observed Odds Ratio compared to Reference | Percent Improved minus Reference Percent Improved |
|---|---|---|---|---|---|---|
| Regrading, Revegetation, Daylighting **(Reference)** | 37 | 16 | 18 | 47.1 | --- | --- |
| Regrading, Revegetation, Daylighting, Special Handling | 18 | 5 | 10 | 33.3 | 0.563 | -13.8 |
| Regrading, Revegetation, Daylighting, Alkaline Addition <100 | 14 | 4 | 8 | 33.3 | 0.563 | -13.8 |
| Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100 | 12 | 4 | 8 | 33.3 | 0.563 | -13.8 |
| Regrading, Revegetation, Daylighting, Special Handling, Water Handling | 8 | 2 | 6 | 25.0 | 0.375 | -22.1 |

**Observed Percentage Improvement**: On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping

**Observed Odds of Improvement**: Number improved or eliminated divided by number with no significant difference

**Ratio of Odds**: What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

## 6.4 Discussion

### 6.4.1 Observed Results

The combinations of BMPs affecting the most discharges at the completed Pennsylvania remining sites in order of decreasing frequency of occurrence are as follows:

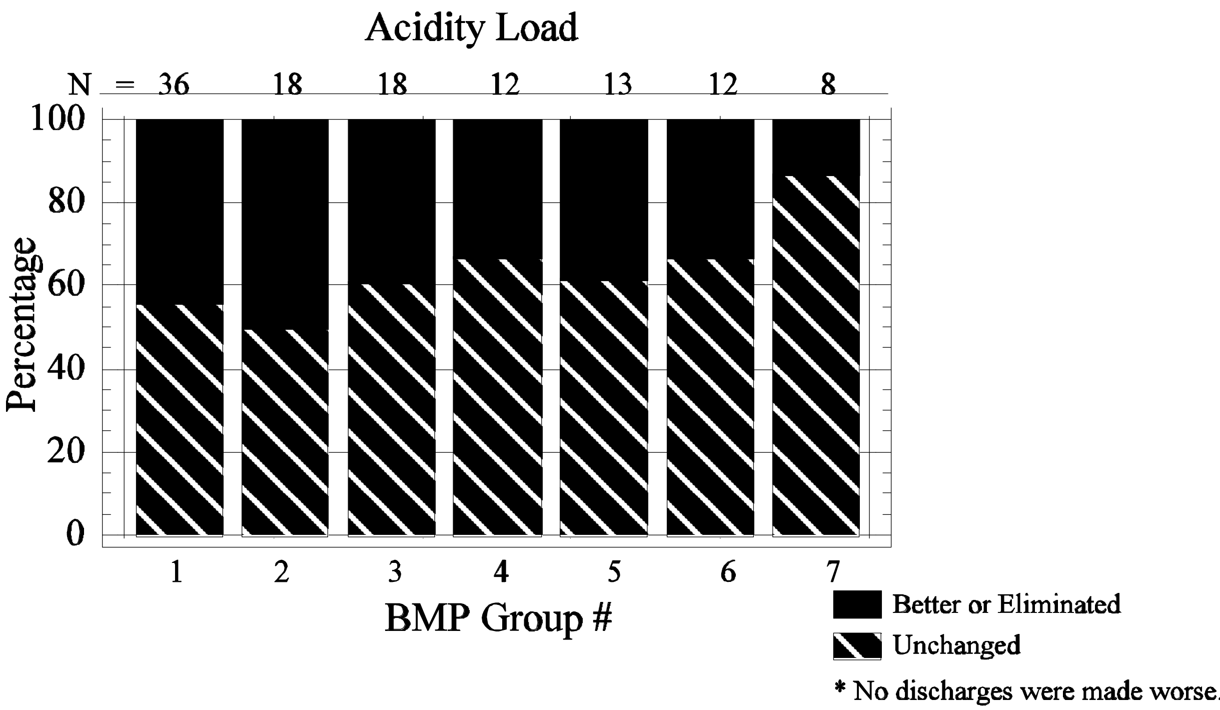
| Group # | | Discharges Affected |
|---|---|---|
| 1 | Daylighting, Regrading, Revegetation | 37 |
| 2 | Regrading, Revegetation | 18 |
| 3 | Daylighting, Regrading, Revegetation, Special Materials Handling | 18 |
| 4 | Daylighting, Regrading, Revegetation, Special Materials Handling, Alkaline Addition (<100 tons/acre) | 12 |
| 5 | Daylighting, Regrading, Revegetation, Alkaline Addition (<100 tons/acre) | 14 |
| 6 | Daylighting, Alkaline Addition (<100 tons $CaCO_3$ equivalent/acre) | 12 |
| 7 | Daylighting, Regrading, Revegetation, Special Materials Handling, Special Water Handling Facilities | 8 |

***Acidity Loading***

Only three BMPs (regrading, revegetation, and daylighting) were reported to be used singly at the Pennsylvania study remining sites (Table 6.2b). Of these BMPs, only daylighting impacted acidity loading in a significant number of discharges (13). Daylighting alone significantly improved 30.8 percent of the discharges for acidity loading with no discharges significantly degraded. Revegetation used singly significantly improved acidity loading in 40 percent of 5 discharges affected with the remainder unchanged. Regrading used singly affected one discharge which was shown to be significantly improved. However, it is doubtful that regrading was used without corresponding revegetation.

The seven most common BMP groups (listed previously) were highly successful in not degrading the discharges in terms of acidity loadings. All of the discharges affected by these BMP groups were either significantly improved or unchanged (Figure 6.4a) with improvement ranging from 12.5 to 50 percent of the discharges depending on BMP group. No discharges were significantly degraded. The most successful BMP combination was regrading and revegetation (#2), followed by daylighting, regrading, and revegetation (#1), and daylighting, regrading, revegetation, and alkaline addition (#5). BMP group #2 significantly improved 50 percent of the discharges and had no significant effect on 50 percent of the discharges. Over 44 percent of the discharges were improved under BMP group #1 with the remainder unchanged. The success of these BMP combinations (#1 and #2) in decreasing acidity loading may be due to the fact that these BMP groups are generally used for remining operations that are environmentally uncomplicated and do not require elaborate BMP plans to effect improvement. Additionally, these BMPs greatly impact the amount of water moving through the reclaimed site and, to a lesser extent, effect the water quality. This may be an indication that flow-reducing BMPs may be more effective in reducing loads than those that work primarily geochemically. This determination is supported by Smith (1988) and Hawkins (1995) who both observed flow to be the predominant determinant of pollution loadings (see Section 1.2, Figure 2.1a).

**Figure 6.4a: Impacts of BMP Combinations on Acidity Loading**



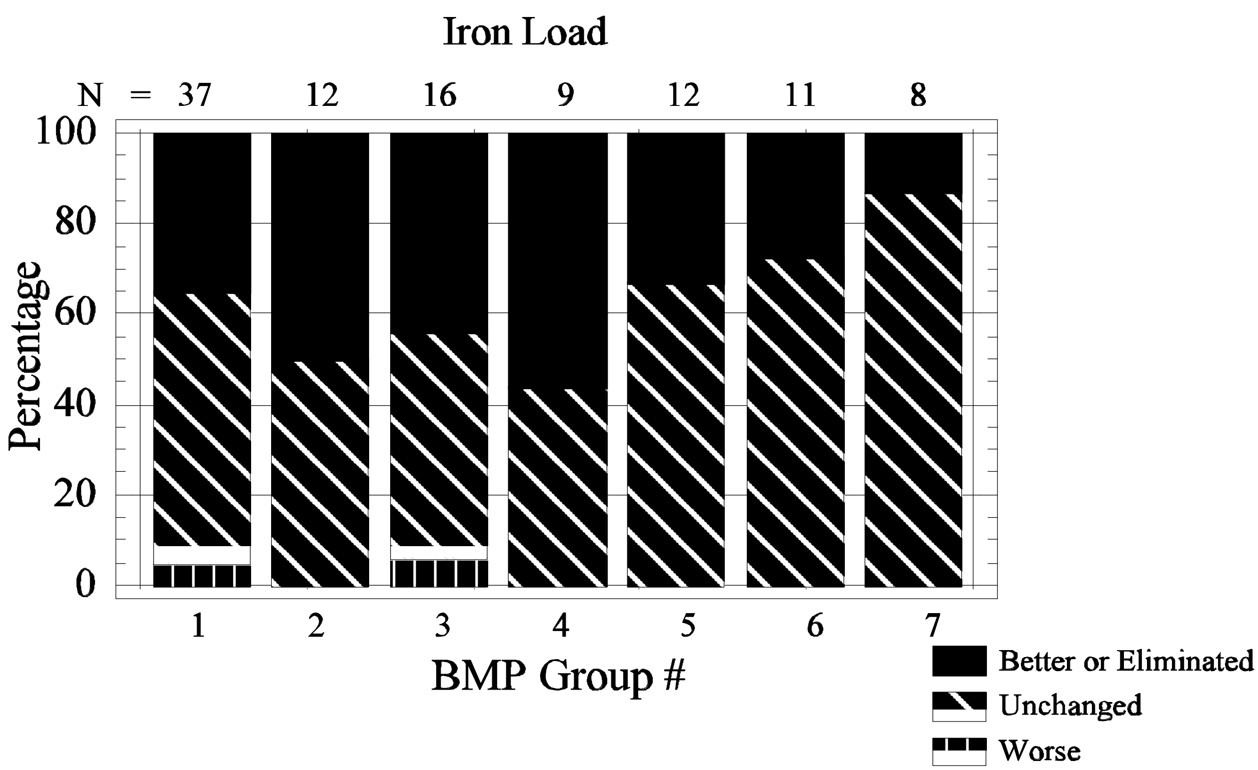

***Iron Loading***

As previously stated, only three BMPs (regrading, revegetation, and daylighting) were reported to be used singly at the Pennsylvania study remining sites and of these BMPs, only daylighting impacted a significant number of discharges (12) for iron loadings. Daylighting singly improved more than half (58 percent) of the discharges for iron loading and had no effect on the remaining 42 percent. No discharges were significantly degraded. Revegetation alone significantly improved 20 percent of discharges (1 discharge), significantly degraded 20 percent of the discharges and did not affect the remaining discharges. Regrading alone was shown to be used for one discharge which was unchanged. However, as previously stated, it is doubtful that regrading was used without corresponding revegetation.

The seven BMP combinations quite successfully left most of the discharges improved or unchanged in terms of the iron load. The two most successful BMP combinations for discharge iron load improvement were daylighting, regrading, revegetation, special materials handling, and alkaline addition (#4) which improved 55.6 percent of the discharges and regrading, revegetation, and alkaline addition (#8) which improved 50 percent of the discharges. The remaining discharges affected by those two BMP groups were unchanged.  Implementation of two other BMP groups (daylighting, regrading, and revegetation (#1) and daylighting, regrading, revegetation and special materials handling (#3)), resulted in a few discharges exhibiting higher iron loadings (failures). The failure rates were 5.4 and 6.7 percent, respectively. However, the actual number of degraded discharges for either BMP group was small, a total of 2. The impact of the seven BMP groups on iron loading rates is illustrated in Figure 6.4b.

The two BMP groups with the highest iron loading improvement rates (#4 and #2) included alkaline addition (<100 tons per acre), which may have raised the pH of the water enough to permit some of the iron to precipitate within the backfill. However, two other BMP groups with that level of alkaline addition (#5 and #6) did not exhibit similar rates of iron loading improvement.  This situation can occur in cases where a large amount of acidic material is encountered during daylighting and naturally occurring alkaline material was not present in the overburden. The amount of alkaline addition may have been insufficient to offset the acidity production.

**Figure 6.4b: Impacts of BMP Combinations on Iron Loading**



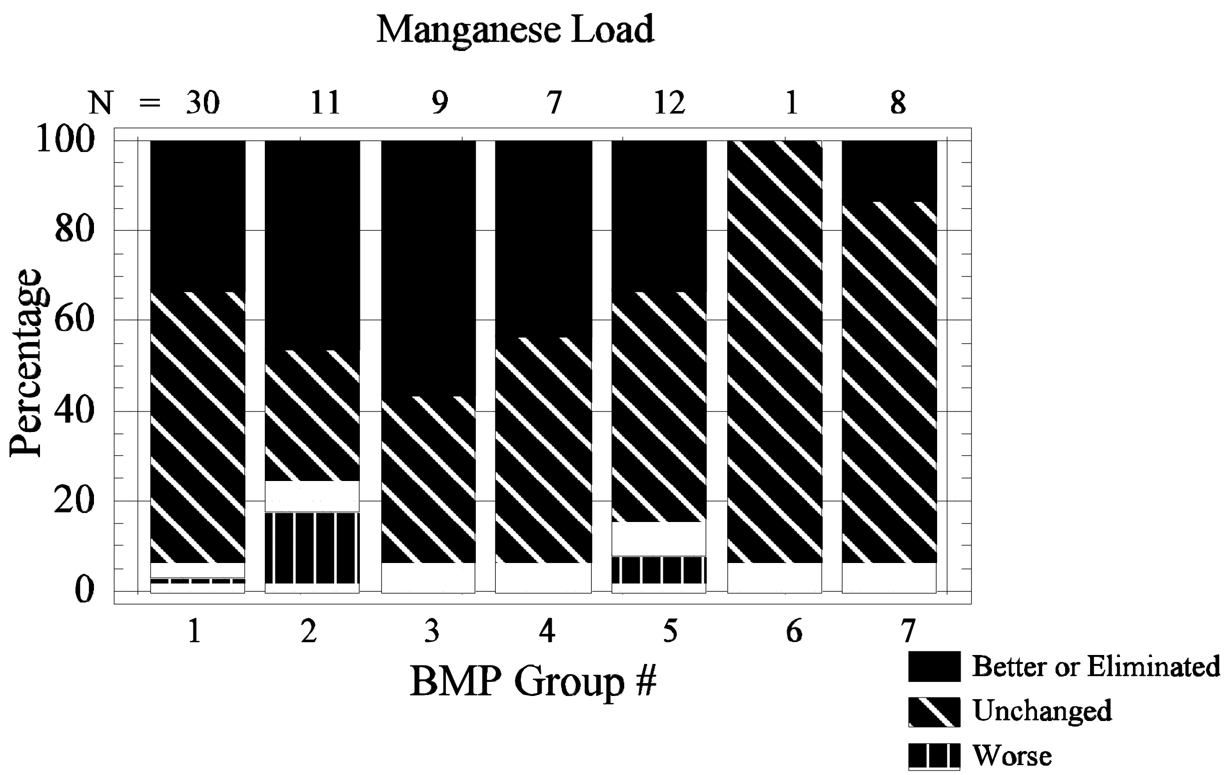
### *Manganese Loading*

Of the three BMPs (regrading, revegetation, and daylighting) used singly at the Pennsylvania study remining sites, only daylighting impacted manganese loading in a significant number of discharges (11). Daylighting singly improved 54.5 percent of the discharges for manganese loading with 9.1 percent (one discharge) significantly degraded. Revegetation significantly improved one (20 percent) of five discharges and did not affect the remaining discharges. Implementation of regrading affected one discharge which was significantly degraded.

Two of the BMP groups induced some of the highest improvement rates observed for any of the contaminant loadings (see Figure 6.4c). The combinations of regrading and revegetation (#2) and daylighting, regrading, revegetation and special materials handling (#3) exhibited discharge improvement rates for manganese of 45.5 and 55.6 percent, respectively. It is difficult to determine what may have allowed these two BMP combinations to be so effective. Manganese concentrations are extremely difficult to predict. Exactly where manganese originates is unclear. However, the main source of manganese appears to be as a solid-solution replacement of iron in siderite ($FeCO_3$) (Rose and Cravotta, 1998). The actual amount of manganese replacement is quite low (~1 percent) (Rose, 1999). Ongoing research may improve the predictive capabilities.

The highest rates of discharge degradation (failure) for the seven BMP groups were exhibited for manganese loadings. Three of seven BMP combinations had at least one discharge that was degraded with respect to manganese loadings. BMP groups regrading and revegetation (#2) and regrading, revegetation, daylighting, and alkaline addition (#5) exhibited the highest failure rates of 18.2 and 8.3 percent, respectively. It is interesting to note that the highest discharge failure rate for manganese loading occurred with BMP group #2, which also had the second highest manganese loading improvement rate. This illustrates the problematic nature of manganese effluent predictions.

**Figure 6.4c: Impacts of BMP Combinations on Manganese Loading**

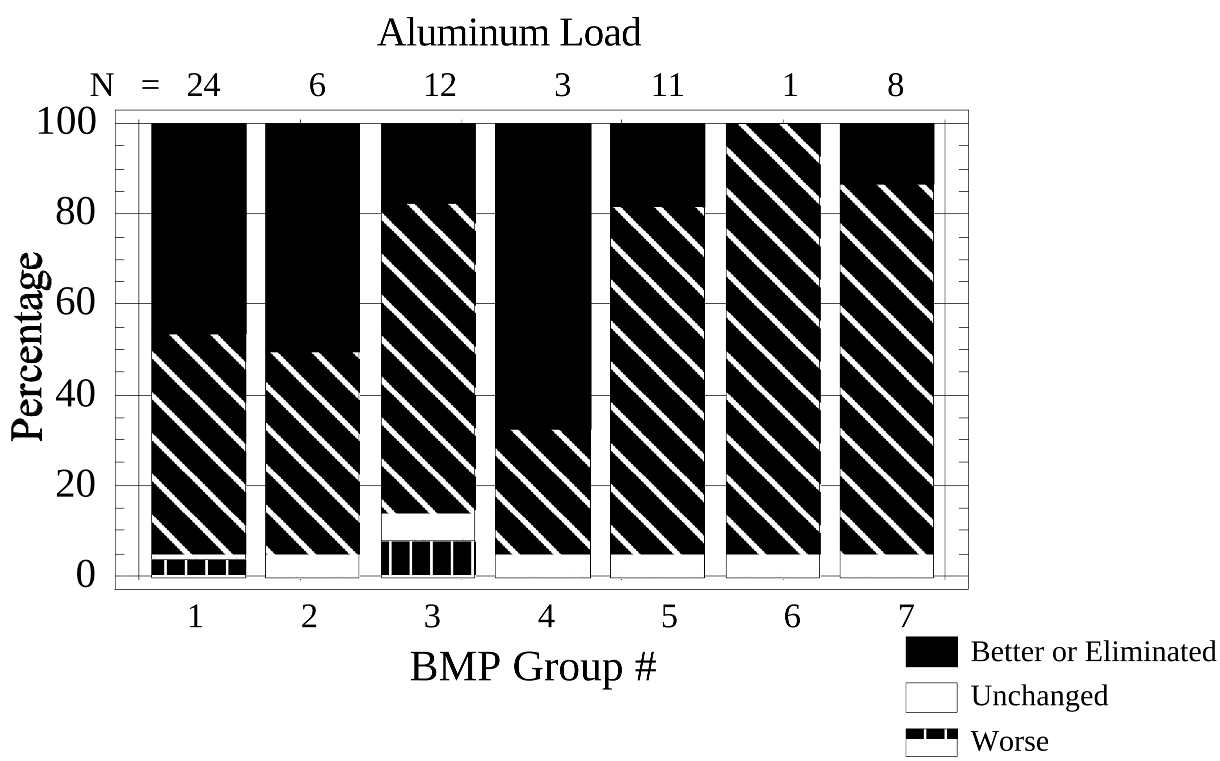



***Aluminum Loading***

Of the three BMPs (regrading, revegetation, and daylighting) reported to be used singly at the Pennsylvania study remining permits, only daylighting impacted a significant number of discharges (10) for aluminum loadings. Daylighting implemented alone significantly improved 40 percent of the affected discharges for aluminum loading and significantly degraded 10 percent (one discharge). Revegetation significantly improved 60 percent of the five affected discharges and had no effect on the remaining two discharges. Regrading implemented alone affected one discharge which was shown to be significantly improved.

The most successful BMP group in improving the aluminum loads was daylighting, regrading, revegetation, special materials handling, and alkaline addition (#4) with 66.7 percent of the discharges exhibiting significant improvement. This was the highest improvement rate exhibited by any of the BMP groups for any of the contaminants, although this group affected only 3 discharges in terms of aluminum loading.  BMP groups of daylighting, regrading, and revegetation (#1) and regrading and revegetation (#2) were the next most successful in improving the aluminum loadings with 45.8 and 50 percent improvement, respectively.

**Figure 6.4d:   Impacts of BMP Combinations on Aluminum Loading**

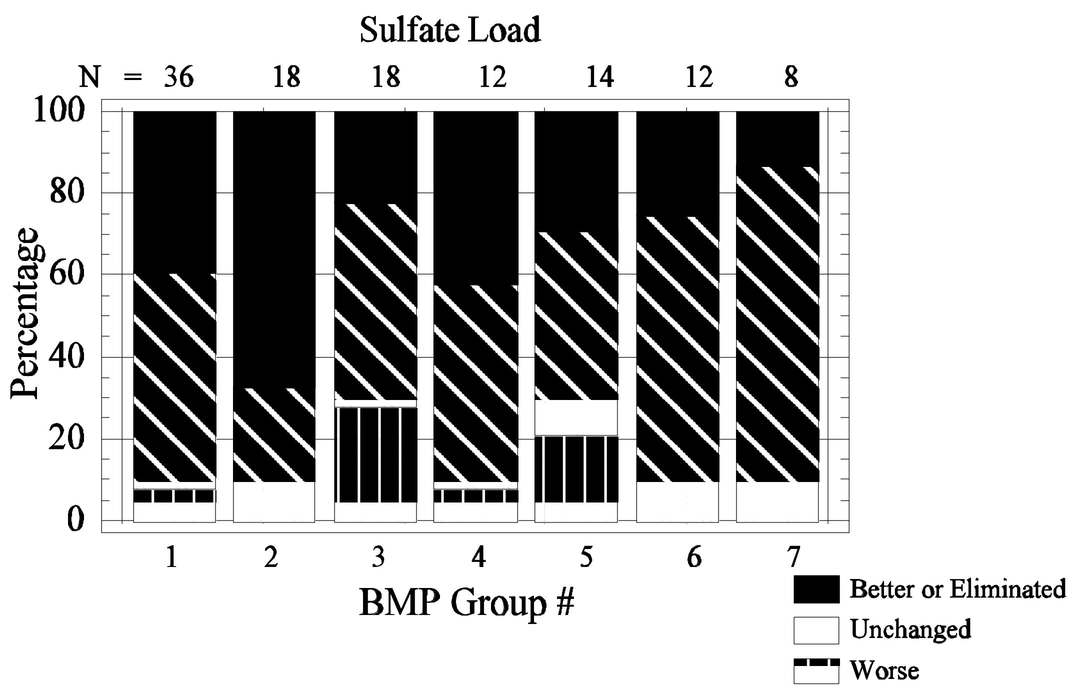



***Sulfate Loading***

As previously stated, sulfate loading is not a regulated effluent parameter, but is included herein to permit a clearer analysis of the effectiveness of BMPs to geochemically reduce the acidity, iron, manganese, and aluminum loadings. Of the three BMPs (regrading, revegetation, and daylighting) reported to be used singly at the Pennsylvania study remining sites, only daylighting impacted sulfate loading in a significant number of discharges (14). Daylighting singly improved 28.6 percent of the discharges for sulfate loading with 14.3 percent (two discharges) significantly degraded. Revegetation significantly improved three (60 percent) of five discharges, did not affect one discharge, and significantly degraded one discharge. Implementation of regrading affected one discharge which was improved.

The most successful BMP group in improving sulfate loading was regrading and revegetation (#2) with 55.6 percent. The next two most successful BMP combinations were daylighting, regrading, revegetation, special materials handling, alkaline addition < 100 tons/acre (#4) and daylighting, regrading, and revegetation (#1) exhibiting improvements of 41.7 and 38.9 percent, respectively. The presence of regrading and revegetation in the three most successful groups indicates that simply reclaiming an abandoned site may greatly decrease acid production.

**Figure 6.4e: Impacts of BMP Combinations on Sulfate Loading**

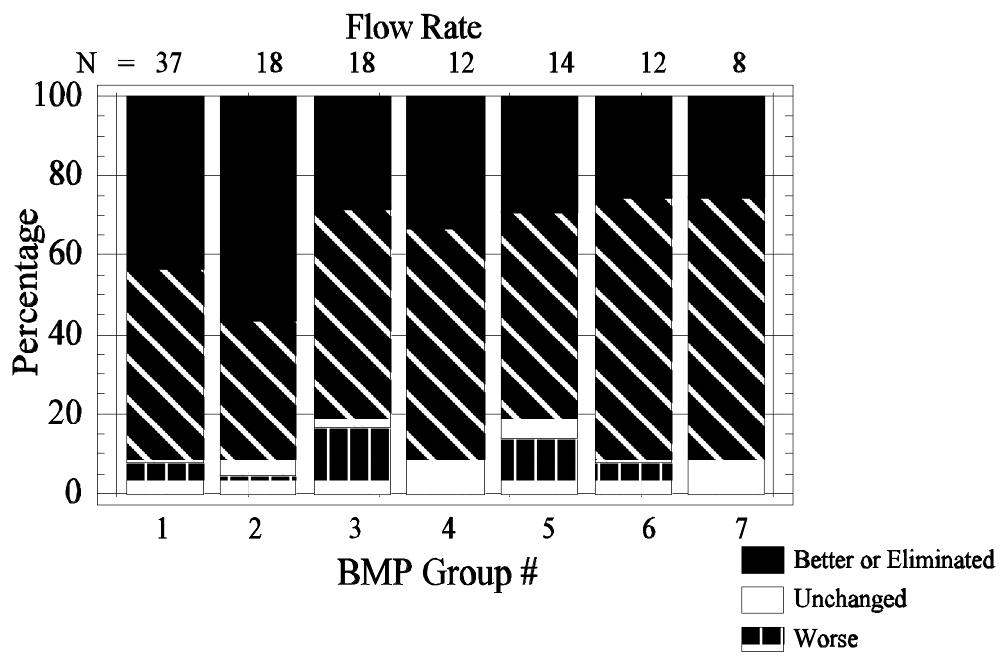


### *Flow Rate*

As previously stated, flow rate is not a regulated effluent parameter, but is included herein to permit a clearer analysis of the effectiveness of BMPs that work to physically reduce the pollution loadings. Of the three BMPs (regrading, revegetation, and daylighting) used singly at the Pennsylvania study remining sites, only daylighting impacted flow rate in a significant number of discharges (14). Daylighting singly improved (decreased or eliminated flow) 28.6 percent of the discharges, with none of the discharges significantly increasing in flow. Revegetation significantly improved three (60 percent) of five discharges and effected no change of the remaining discharges. Implementation of regrading affected one discharge which was unchanged.

The most successful BMP group in improving flow rate was regrading and revegetation (#2) with 66.7 percent, followed by daylighting, regrading, and revegetation (#1) and daylighting, regrading, revegetation, special materials handling, alkaline addition < 100 tons/acre (#4) exhibiting improvements of 43.2 and 33.3 percent, respectively. As with sulfate, the presence of regrading and revegetation in both these groups, indicates that simply reclaiming a site will reduce infiltration into the spoil, which ultimately reduces the outflow.

**Figure 6.4f: Impacts of BMP Combinations on Flow Rate**




### 6.4.2 Predicted Results

The data obtained from the Pennsylvania study remining sites were statistically analyzed using the methodology described in Section 6.3.1. These analyses, applied to single BMPs, determined the predicted percentage of discharges that would be improved, the odds that a discharge would be improved, and the odds of improvement over doing nothing at all in terms of BMPs. The results of these analyses are listed in Tables 6.3a through 6.3d (BMPs implemented alone). Tables 6.3e and 6.3f are the same analyses conducted for sulfate loadings and flow rate to allow for an in depth determination of the possible impacts (physical or geochemical) of specific BMPs and BMP combinations.

### 6.4.2.1 *BMPs Implemented Alone*

Acidity Loading

The predicted probabilities of improvement for all of the single-use BMPs (Revegetation, Regrading, and Daylighting) range from 27.4 to 50.1 percent. The remaining BMPs were not implemented alone, and therefore, do not have associated observed results. However, the statistical analyses can provide some insight into their efficiency. Alkaline redistribution (80.9 percent) and biosolids addition (71.5 percent) exhibit the highest predicted probabilities of improvement of acidity loading of all of the BMPs followed by special water handling (71.4 percent), mining alkaline strata (64.2 percent) and coal refuse removal (57.6 percent). It is interesting to note that alkaline addition of <100 tons per acre yielded the lowest predicted improvement probability of 25.4 percent, while half of the four highest predicted percentages also deal with increasing the amount of alkaline material in the backfill. The results may indicate that the amount of alkaline material added (<100 tons per acre) was too low. Brady and others (1990) observed that alkaline addition application rates at surface mines frequently are too low to improve the water quality.

The significant interaction between special handling and water handling indicates that the positive effect of water handling on the odds of at least improvement is greatly diminished when special handling is also present. This can be best explained by comparing the observed results for water handling with and without special handling (see Table 6.2b). When water handling and special handling both affect a discharge, the result is at least improvement 11 percent (1 out of 9 discharges) of the time. However, when water handling but not special handling affect a discharge, the result is at least improvement 77 percent (10 out of 13 discharges) of the time. It is worth noting that these two BMPs never affect a discharge without being combined with other BMPs. Eight of the nine discharges affected by both water handling and special handling were affected additionally by regrading, revegetation and daylighting. The failure of special handling may be because it is frequently employed where a substantial amount of acid-forming materials is present, perhaps too much to be offset by any single BMP or group of BMPs.

<u>Iron Loading</u>

Predicted probabilities of improvement in iron loading for all of the single-use BMPs range from 36.0 to 51.3 percent. Special water handling facilities (73.1 percent) and biosolids addition (62.9 percent) exhibit the highest predicted improvement percentages followed by alkaline redistribution (61.3 percent), revegetation (51.3 percent) and mining of alkaline strata (49.7 percent). The lowest predicted probability of improvement is coal refuse removal (26.2 percent). The relatively low number of discharges affected (7) may bring into question the usefulness of this prediction value. In addition, the low predicted discharge improvement may be due to a delayed response in regards to water quality, compared with other BMPs. Refuse is typically acid-producing and when removed, fresh refuse is exposed to weathering or flushing of existing weathered products. It may take more time than the limited monitoring periods available to see improvements in some water quality parameters.

The significant interaction between special handling and water handling indicates that the positive effect of water handling on the odds of at least improvement is greatly diminished when special handling is also present. This can be best explained by comparing the observed results for water handling with and without special handling (see table 6.2b). When water handling and special handling both affect a discharge, the result is at least improvement 20 percent (2 out of 10 discharges) of the time. However, when water handling but not special handling affect a discharge, the result is at least improvement 75 percent (9 out of 12 discharges). It is worth noting that these two BMPs never affect a discharge without being combined with other BMPs. Eight of the ten discharges affected by both water handling and special handling were also affected by regrading, revegetation and daylighting.

Manganese Loading

Predicted probabilities of discharge improvement for single-use BMPs range from 44.6 to 54.0 percent. Alkaline material redistribution (92.6 percent) and biosolids application (96.1 percent) exhibit the highest predicted improvement, followed by water handling (90.4 percent), mining alkaline strata (68.8 percent) and special handling (60.3 percent). The lowest probabilities of improvement were predicted for coal refuse removal (2.8 percent) and alkaline addition >100 tons per acre (6.2 percent). However, these BMPs each affected 6 discharges and the strength of the prediction is weak. In addition, an improvement in manganese loading in discharges affected by coal refuse removal may be delayed as explained in regards to iron loading.

The significant interaction between special handling and water handling indicates that the positive effect of water handling on the odds of at least improvement is greatly diminished when special handling is also present. This can be best explained by comparing the observed results for water handling with and without special handling (see table 6.2b). When water handling and special handling both affect a discharge, the result is at least improvement 22 percent (2 out of 9 discharges) of the time. However, when water handling but not special handling affect a discharge, the result is at least improvement 88 percent (7 out of 8 discharges) of the time. It is worth noting that these two BMPs never affect a discharge without being combined with other BMPs.

Aluminum Loading

The number of discharges (117) analyzed for aluminum loading is considerably lower than for any of the other contaminants. Therefore, the results of the statistical analyses are much less definitive. The predicted probabilities of improvement for single-use BMPs ranges from 43.0 to 61.2 percent. Biosolids application (96.4 percent) and alkaline material redistribution (93.3 percent) exhibit the highest improvement predictions, followed by regrading (21.2 percent), special water handling (59.5 percent) and revegetation (55.0 percent). The lowest improvement predictions are for coal refuse removal (34.0 percent) and mining of high-alkaline strata (26.1 percent). However, these BMPs impacted 6 and 3 discharges respectively, and the strength of the prediction is questionable. In addition, an improvement in aluminum loading in discharges affected by coal refuse removal may be delayed as explained in regards to iron and manganese loading.

Sulfate Loading

Predicted probabilities of discharge improvement for single-use BMPs range from 12.3 to 75.1 percent. Alkaline material redistribution (80.1 percent) and biosolids application (76.0 percent) exhibit the highest predicted improvement of all of the BMPs, followed by mining alkaline strata (65.4 percent). The lowest probabilities of improvement were predicted for coal refuse removal (9.0 percent) and special handling (10.8 percent).

Flow Rate

Predicted probabilities of discharge improvement for single-use BMPs range from 19.5 to 66.0 percent. Mining of alkaline strata (88.7 percent), biosolids addition (80.4 percent), and alkaline redistribution (66.3 percent) exhibit the highest predicted improvement of all of the BMPs, followed by alkaline addition < 100 tons per acre with 52.3 percent. The lowest probabilities of improvement were predicted for coal refuse removal (1.4 percent) and special handling (12.7 percent).

#### 6.4.2.2 *BMP Groups*

The term “remining” implies that mining will be occurring on an area that has been previously mined. Specifically, for the sake of this manual, it also implies that the area was mined prior to implementation of SMCRA (1977) and modern reclamation standards. There are four basic types of abandoned mine lands that are remined: (1) sites that were previously surface mined, (2) sites that were previously underground mined, (3) sites that were previously surface mined and underground mined, and (4) sites that had coal refuse deposited on the surface. These areas cannot be reaffected or remined without implementation of some minimal BMPs. Table 6.4a shows the type of previous mining and the associated minimal BMP(s).

**Table 6.4a: Types of Mining and Minimal BMPs**

| Type of Previous Mining | Minimal Best Management Practices |
|---|---|
| Surface Mining | Regrading, Revegetation |
| Underground Mining | Daylighting |
| Surface and Underground Mining | Regrading, Revegetation and Daylighting |
| Refuse Disposal | Refuse Removal, Regrading, Revegetation |

Of the discharges affected by remining, 156 were affected by regrading, 170 by daylighting and only 9 by coal refuse removal. There were also a large number of discharges that were affected by both regrading and daylighting. Nearly all discharges affected by regrading were also affected by revegetation. The group of regrading and revegetation and the group of daylighting occurred enough times that it was possible to compare the effectiveness of these minimum BMPs against the minimum BMPs plus other select BMPs (Tables 6.3g through 6.3r). Likewise, the group of regrading and revegetation combined with daylighting, together, affected enough discharges for similar evaluation (Table 6.3s through 6.3x). These minimum BMP combinations were compared against the minimum combination plus select other BMPs. The BMP groups were selected based on their having affected at least four discharges that did not get significantly worse. The BMP groups were evaluated for effects on flow and for effects on acidity, iron, manganese, aluminum and sulfate loadings.

Unfortunately some BMPs that had a high rate of success (i.e., alkaline redistribution, mining of alkaline strata and alkaline addition at application rates greater than 100 tons per acre, Table 6.3a) could not be evaluated because they affected too few discharges.

Results of the evaluations of BMP groups are reported in Tables 6.3g through 6.3x. Interpretation of these tables is as follows:

- The first BMP group represents the reference BMP(s).
- If the observed percent improved is greater than the percent improved by the reference group. This suggests that the combined BMPs may have been more effective than the reference group.
- If the observed odds ratio is greater than one, the combined BMPs were possibly more effective than the reference BMP group.
- If the observed odds ratio is less than one, the combined BMPs were possibly less effective than the reference BMP group.
- If the percent improved minus the reference group percent improved is positive, the combined BMPs may have been more effective than the reference group used alone. If negative, the combined BMPs were possibly less effective.

Interpretation of these results cannot be made blindly. A combination of BMPs that is less effective than the reference does not necessarily imply that the "added" BMP(s) are detrimental. It should also be kept in mind that the comparisons are between discharges that had pre- and post-mining water quality that was not statistically different versus pre- and post-mining water quality that showed at least a statistically significant improvement (improved or eliminated) after remining. Failures were not evaluated because they were so infrequent. Climatic differences also were not taken into account.

Regrading and Revegetation

Regrading and revegetation, as mentioned above, are the basic BMPs required for reclamation of previously surface mined land. They occur together, but without other BMPs, to affect at least 18 discharges. Tables 6.3g through 6.3l compare the success of regrading and revegetation, against regrading and revegetation in addition to other select BMPs for acidity, iron, manganese and aluminum loading. Tables 6.3k and 6.3l show the analysis of sulfate loadings and flow rate.

*Acidity Loading* (Table 6.3g): Of the discharges affected by this BMP reference group, the number of discharges that stayed the same and that at least improved, in regards to acidity, were the same. One other BMP group (regrading revegetation, and special handling) had similar results, although the sample size was the minimum of four. Only one BMP combination (regrading, revegetation, and water handling) performed better than the reference. Again the sample size was the minimum, but all four samples improved or were eliminated. All other BMP combinations performed less effectively than the reference group. The least effective BMP combination was regrading, revegetation, daylighting, special handling, and water handling, with only one of eight discharges improving.

*Iron Loading* (Table 6.3h): Two of seven BMP combinations were more effective than the reference group, and one was as effective, in regards to at least improving iron loading, than the control. The most effective BMP group was water handling combined with the reference BMPs. Iron in all four of the discharges effected, either was improved or eliminated. The least effective BMP combination was that of regrading, revegetation, daylighting, special handling, and water handling, where only one of eight discharges improved.

*Manganese Loading* (Table 6.3i): Again, the combination of regrading, revegetation and water handling proved the most effective BMP combination, with all four discharges showing improvement or elimination. This was the only combination that was more successful than the reference BMP group. The combination of regrading, revegetation, daylighting, special handling, and water handling, again proved least effective. In general, manganese had the most failures (resulted in the most discharges with loadings that were significantly unchanged) of any parameter. As discussed in Section 6.4.1, the ability to predict manganese is severely limited.

*Aluminum Loading* (Table 6.3j): Results for aluminum loading were reported less often than were results for the other parameter loadings, and less BMP combinations are available for comparison to the reference. Although all BMP combinations performed less effectively than the reference group in regards to aluminum loading, the combination of regrading, revegetation, daylighting, special handling and water handling was the least effective.

*<u>Sulfate Loading</u>* (Table 6.3k): As for other parameters, the combination of regrading, revegetation and water handling proved the most effective BMP combination, with three of four discharges (75.0 percent) showing improvement or elimination. This was the only combination that was more successful than the reference BMP group with 58.8 percent. The combinations of regrading, revegetation, and special handling and regrading, revegetation, and alkaline addition < 100 tons proved least effective with no discharges exhibiting improvement.

*<u>Flow Rate</u>* (Table 6.3l): As for other parameters, the combination of regrading, revegetation and water handling proved the most effective BMP combination, with three of four discharges (75.0 percent) showing improvement or elimination. This was the only combination that was more successful than the reference BMP group with 66.7 percent. The BMP combination of regrading, revegetation, daylighting, special handling and water handling was the least effective.

*<u>Overall</u>*

The BMP reference group of regrading and revegetation includes BMPs that are effective for reducing pollution load by reducing flow. This is reflected by the fact that half the discharges using only these BMPs showed improvement (Tables 6.3g through 6.3l). Most of the other BMPs in the groupings are BMPs that are typically applied to sites that have acidic materials and/or a lack of calcareous rocks. These BMPs are "geochemical" and affect water chemistry rather than flow. The reference group out-performed 6 of the 8 other groupings that were compared. This is probably because, in cases where regrading and revegetation were used alone, the overburden was of good quality and there was no need for additional BMPs. The implementation of special handling and alkaline addition imply that there was acidic material present and a lack of calcareous rocks. Special handling of acidic materials, alone, may reduce acid production, but cannot produce alkaline drainage. Alkaline addition, where it does occur in a comparison group, is always less than 100 tons/acre. It has been shown by various studies, that addition rates less than 100 tons/acre are not generally capable of producing alkaline drainage. It should be kept in mind that alkaline drainage is not necessarily a goal of remining sites, the goal is that the water not get worse. The BMP comparisons with alkaline addition at less than 100 tons per acre do suggest that alkaline addition rates greater than 100 tons per acre could result in more improvements.

For acidity, iron, and manganese, the most effective BMP combination that included the reference group was that of regrading, revegetation, and water handling. Water handling is a physical BMP and may have further reduced flow which would further reduce load. The BMP combination that consistently performed the worst was regrading, revegetation, daylighting, special handling, and water handling. This combination performed poorly for each parameter and for each evaluation of reference BMPs. There is no intuitive explanation for this. Daylighting generally results in acidic materials that need to be handled, and the inclusion of special handling implies that this was the case.

Daylighting

Daylighting is the minimum BMP required when an abandoned underground mine exists within a coal seam proposed for surface mining. Daylighting by itself occurred 14 times and was associated with 7 other BMP combinations that occurred at least 4 times.

*Acidity Loading* (Table 6.3m): Daylighting implemented alone improved or eliminated acidity loading in four affected discharges, and resulted in no change in nine discharges. Six of the seven BMP combinations were more effective than the reference combination. The least effective performance was for the same least effective combination in respect to regrading and revegetation (regrading, revegetation, daylighting, special handling, and water handling).

*Iron Loading* (Table 6.3n): Daylighting implemented alone resulted in the improvement of seven discharges, and resulted in no change in the remaining five discharges. None of the 7 BMP combinations were as effective as the control. The least effective combination was the same as the least effective combination in regards to acidity (regrading, revegetation, daylighting, special handling, and water handling).

*Manganese Loading* (Table 6.3o): Six of the discharges affected by the reference group in terms of manganese loading, improved or were eliminated and four remained unchanged. No BMP combination was more effective than the reference combination. The least effective combination was the same as the least effective combination in regards to acidity and iron (regrading, revegetation, daylighting, special handling, and water handling).

*Aluminum Loading* (Table 6.3p): Because fewer data were available in regards to aluminum, there are only four BMP combinations that were compared to the reference group. One of these combinations (regrading, revegetation, and daylighting), was slightly more effective than the control group. The other three combinations were less effective, with the least effective combination being the same as the least effective combination in regards to acidity and iron and manganese (regrading, revegetation, daylighting, special handling, and water handling).

*Sulfate Loading* (Table 6.3q): Four of the discharges (33.3 percent) affected by the reference group in terms of sulfate loading, improved or were eliminated and eight remained unchanged. Three BMP groups (regrading, revegetation, and daylighting; regrading, revegetation, daylighting, and alkaline addition < 100 tons/acre; and regrading, revegetation, daylighting, special handling and alkaline addition < 100 tons/acre) were more effective than the reference combination. The least effective combination was the same as the least effective combination in regards to the other parameters (regrading, revegetation, daylighting, special handling, and water handling) with 12.5 percent.

*Flow Rate* (Table 6.3r): Two of the discharges (14.3 percent) affected by the reference group in terms of flow, improved or were eliminated and 12 remained unchanged. All of the seven BMP combinations were more effective than the reference group. The least effective BMP group other than the reference group, was daylighting, regrading, and revegetation and regrading, revegetation, daylighting, special handling, and water handling.

*Overall*

The percentage of discharges that improved in regards to acidity from the implementation of daylighting alone (Table 6.3m), is less than the percentage that improved from the implementation of regrading and revegetation alone (Table 6.3g). Percentages of improved discharges were 30.8 and 50 respectively. This result is not surprising because, daylighting often results in a large amount of acidic material that is spoiled. It is interesting that six of the seven groupings, when compared to the reference group, were more effective in regards to acidity loading. This suggests that many of the BMPs, such as special handling and alkaline addition (even applied at lower rates), helped to offset some of the natural potential of these sites to produce acidic water.

The least effective BMP group was again the combination of regrading, revegetation, daylighting, special handling and water handling.

Regrading, Revegetation, and Daylighting

A large number of remining operations encountered both abandoned surface mines and underground mines. Therefore, the minimum BMPs implemented at these sites, are a combination of those in the first two reference groups, namely regrading, revegetation, and daylighting.

*Acidity Loading* (Table 6.3s): A total of 36 discharges were affected by the reference BMP group. Sixteen discharges were improved or eliminated and twenty remained unchanged. Four other BMP combinations affected enough discharges to be compared to the reference group. None were as effective as the reference group (although three of the four were only slightly less effective). The least effective, as in all cases cited thus far, was the combination of regrading, revegetation, daylighting, special handling, and water handling.

*Iron Loading* (Table 6.3t): Thirty-seven discharges were affected by the reference BMP group. Thirteen were improved or eliminated and 22 remained unchanged. Two of the four BMP groups (regrading, revegetation, daylighting and special handling; and regrading, revegetation, daylighting, special handling, and alkaline addition less then 100 tons per acre) were more effective than the reference group. A third group (regrading, revegetation, daylighting, and alkaline addition less than 100 tons/acre) was almost as effective as the reference group. The least effective, again, was the combination of regrading, revegetation, daylighting, special handling, and water handling.

*Manganese Loading* (Table 6.3u): Thirty discharges were affected by the reference BMP group in terms of manganese loading. Ten were improved or eliminated and 19 remained unchanged. Three of the four BMP groups were more effective than the reference group. The least effective, again, was the combination of regrading, revegetation, daylighting, special handling, and water handling.

*Aluminum Loading* (Table 6.3v): Twenty-four discharges were affected by the reference BMP group in regards to aluminum loading. Eleven were improved or eliminated and 12 remained unchanged. All three other BMP combinations that affected enough discharges to allow comparison to the reference group, were less effective than the reference group in terms of at least improving aluminum loading. The least effective, again, was the combination of regrading, revegetation, daylighting, special handling, and water handling.

*Sulfate Loading* (Table 6.3w): Thirty-six discharges were affected by the reference BMP group in regards to sulfate loading. Fourteen (42.4 percent) were improved or eliminated and 19 remained unchanged. Four other BMP groups affected enough discharges to allow for a comparison. Only one of these four BMP groups (regrading, revegetation, daylighting, special handling, and alkaline addition < 100 tons/acre) exceeded the reference group for effectiveness by improving 45.5 percent of the discharges. The group of regrading, revegetation, daylighting, special handling, and water handling was the least effective improving only 12.5 percent.

*Flow Rate* (Table 6.3x): Thirty-seven discharges were affected by the reference BMP group in regards to flow rate. Sixteen (47.1 percent) were improved or eliminated and 18 remained unchanged. Four BMP combinations affected enough discharges to allow for a comparison. None of these four BMP groups exceeded the effectiveness of the reference group. The BMP group of regrading, revegetation, daylighting, special handling, and water handling was the least effective in reducing the flow rate at 25.0 percent improvement.

*Overall*

The effectiveness of the four BMP groups in terms of acidity compared to the reference grouping was always less than that of the reference grouping (Tables 6.3s through 6.3x). The last grouping (regrading, revegetation, daylighting, special handling, and water handling) was again, substantially less effective. Daylighting of underground mines adds additional acidic material to the mine spoil and as discussed under the reference group of regrading and revegetation, if other BMPs are not used the overburden was probably of good quality. If other BMPs are used, the overburden was probably considered problematic (acidic and/or a lack of calcareous strata).

### Coal Refuse Removal

Coal refuse removal is the minimum BMP implemented when mining coal refuse, although an examination of coal refuse removal sites indicates that regrading and revegetation also are typically implemented. BMP groups that included coal refuse removal did not affect a sufficient number of discharges to compare with a reference set. Four discharges were affected by special handling in addition to coal refuse removal, one by biosolids application in addition to coal refuse removal, and one by alkaline addition in addition to coal refuse removal. Special handling of coal refuse, a material that is generally acid producing, is not easy to perform, because it would require special handling of 100 percent of the material. Isolation of 100 percent of the material is not possible. Implementation of biosolids application or alkaline addition are more reasonable. Abandoned coal refuse disposal areas are typically characterized by sparse vegetation and lack of "topsoil." Biosolids could aid in the establishment of a growth medium.

Because refuse is, more often than not, acid producing, the addition of alkaline material would be an appropriate additional BMP. The results of the implementation of coal refuse removal are presented in Table 6.2a, and are discussed below.

*Acidity Loading:* Coal refuse removal affected only 9 discharges in regards to acidity loading. Six discharges were improved or eliminated and three remained unchanged.

*Iron Loading*: Coal refuse removal affected 7 discharges in regards to iron loading. Two discharges were significantly improved or eliminated, four remained the same, and one became significantly worse.

*Manganese Loading:* Coal refuse removal affected 6 discharges in terms of manganese loading. No discharges improved, five remained the same and one was significantly degraded.

*Aluminum Loading*: Coal refuse removal affected 6 discharges in terms of aluminum loading. Two discharges improved, four remained the same and none were degraded.

*Sulfate Loading*: Coal refuse removal affected 9 discharges in terms of sulfate loading. Of these discharges 2 improved and the remainder were unchanged. None exhibited increased loadings (possible increase in acid production).

*Flow Rate*: Coal refuse removal affected 9 discharges in terms of flow rate. One discharge exhibited an improvement (reduced flow rate), while the remaining discharges were unchanged. None showed an increase in flow.

*Overall*

Two thirds of the 9 discharges showed improvements in acidity load. This is not surprising because the removal of coal refuse can only be beneficial. Coal refuse is typically an acid-producing material and is often associated with severe acid mine drainage. Removal of the coal refuse is the removal of an acid-producing material. The two BMPs that typically accompany coal refuse removal are regrading and revegetation. Both of these BMPs tend to decrease water infiltration into the refuse material and thus, tend to decrease load.

Overall Evaluation

Many of the multiple BMP groups when compared with the reference BMP group were not as effective as the reference group. This should not be interpreted to mean that the addition of BMP(s) to the reference groups were not effective or that discharges would have improved if the additional BMPs had not been implemented. The very nature of many of the BMPs that were implemented indicates that they were added to counter either the potential for acid production or to compensate for a lack of naturally-calcareous material. For example, special handling generally implies that acid-forming materials are present; alkaline addition <100 tons per acre suggests that naturally calcareous materials were lacking. Conversely, discharges affected by the minimum BMPs, may have had better quality overburden, and thus, not required additional BMPs. Also, some BMPs listed in Tables 6.3a through 6.3d, that were shown to positively influence water quality (e.g., alkaline redistribution and mining high-alkaline strata), were not used for comparison because of small number of discharges they affected.

In addition, although many of the BMP groups were not as effective as the control group, it is not an indication that they were not successful. The fact is that very few sites in the entire data set got worse. This may not have been the case if these additional BMPs were not used.

The least effective BMP combination was regrading, revegetation, daylighting, special handling and water handling. Only one of eight discharges affected by this BMP combination improved. None of the BMPs in this group will add alkalinity to the mine site and it is known that special handling, in the absence of calcareous rock, will not in-and-of-itself produce alkaline water. Perhaps this should be taken as a sign that alkaline-deficient sites can benefit from alkaline addition. The failure of this group may be due to these sites having considerable problems in terms of contaminant loadings and in order to offset these existing and potential future problems, a variety of BMPs are applied. This sort of a “shotgun approach” to pollution abatement on marginal sites may not be viable.

The low success rate of the BMP group of regrading, revegetation, daylighting, special handling, and water handling also was seen in the significant interaction terms presented in Tables 6.3a, 6.3b, and 6.3c. For acidity, iron, and manganese, there was a significant negative interaction between water handling and special handling. These interactions suggest that the positive effect of water handling on the odds of at least improvement is diminished when special handling is also present. For 89 percent of the discharges (in regards to acidity and manganese) and 80 percent of the discharges (in regards to iron) that were affected by water handling and special handling, the discharges were also affected by regrading, revegetation and daylighting. Of these five BMPs, water handling was the most efficient in dealing with acidity and iron loadings for other discharges. Since special handling and water handling rarely occurred together in BMP groups, the percentage of discharges affected by the combination of the two, that at least improved, was very low. Therefore, the statistical models for acidity and iron isolated these two BMPs as interacting significantly. However, since the interaction was significant, mainly due to this five-BMP group, conclusions about the behavior of these two BMPs combined alone should not be made without first examining why the five-BMP group yielded such low results.

Studies cited earlier by Smith (1988) and Hawkins (1995) showed that reduction in flow is the most significant influence on load reduction. Regrading and revegetation are both significant BMPs in terms of reducing flow. The other BMPs evaluated, with the exception of water handling, are predominantly geochemical BMPs, which would have a less marked effect on flow reduction.

### *Limitations*

As previously stated, this remining water quality data set for pre-existing discharges is the most comprehensive available at this time. However, the results of these analyses should be considered with the following limitations in mind:

- Once the actual subsets of the 231 discharges that were impacted by specific BMPs or BMP combinations are separated out, the number impacted, in some cases, becomes relatively small. In cases where smaller subsets of data represent each BMP or BMP group, the number of results that are statistically significant at the 95 percent confidence level are few.

- The data collected for pre-, during, and post-mining does not take into consideration the variability of precipitation during the sampling periods. Water quality and flow data recorded during unusually low or high precipitation periods can greatly impact determined efficiency results.

- No consideration has been given to the probability that, some discharges within a mine site have gained some or all of the flow that previously went to another. One discharge may appear to have been degraded, while others may appear to have significantly improved. However, the overall pollution load for the hydrologic unit may not have changed or may have substantially improved. With the anticipated changes in the ground water flow system, this scenario is not uncommon.

- Data evaluated included contaminant loading and flow rate information, and did not include contaminant concentration data. For this reason, it is not possible at this time, to determine whether discharge improvement is in terms of water volume, contaminant concentration or both. The effects of geochemical BMPs verses hydrologic control BMPs are difficult to determine. With the evaluation of concentration data, efficiency determinations of individual BMPs and BMP combinations are expected to improve.

## 6.5 Summary

Even with the aforementioned limitations, the analyses strongly indicate the high rate of success of BMPs and BMP combinations implemented at remining operations throughout Pennsylvania. Very few of the single-use BMPs or BMP combinations had less than a 90 percent success rate.

Those BMPs that exhibited a significant failure rate for any pollutant had no more than 2 discharges with significantly higher loadings. The most efficient BMPs varied according to the target contaminant. The number of discharges that were observed to be made worse during remining was so low that they could not be used for meaningful statistical analyses. This is illustrative how successful remining and the use of appropriate BMPs can be when properly implemented.

Remining falls into four categories: (1) reaffecting previously surface mined areas, (2) daylighting of underground mines, (3) refuse removal, and (4) reaffecting previously surface mined areas and daylighting underground mines. Each of these remining activities has minimum BMP(s) associated with them. For example, remining of previously surface mined areas requires regrading and revegetation and where deep mines are present the minimal BMP is daylighting. Minimal BMP groups were determined for each of the above four remining categories. Frequently, in addition to the minimum BMPs, other BMPs were also employed during each of the four remining operations. This allowed a comparison between the minimum BMPs for a category against situations were other BMPs were also used (minimum plus other BMPs). In many instances, the discharges affected by the minimum BMPs plus additional BMPs were less effective (had less "improved" discharges) than the minimal BMPs used alone. This is attributed to the fact that, in situations where more than the minimum number of BMPs were implemented, it was probably due to the presence of acid-forming materials and/or a lack of naturally occurring calcareous rock. In these cases, additional BMPs were added to counter negative characteristics of the mine site overburden. In contrast, remining operations that implemented the minumum BMPs, probably had overburden that was of better quality.

The BMPs predicted to be most efficient for acidity load were those that added alkalinity to the operation, such as mining into alkaline strata and alkaline redistribution. However, when the amount of alkaline material added was small (< 100 tons per acre), the predicted success rate (at least improvement) was one of the lowest (25.4 percent). This amount of added alkalinity was insufficient to successfully prevent or treat AMD production. The finding that BMPs that incorporate calcareous materials into mine spoil have a positive influence on acidity load (i.e., a reduction in load) may seem obvious, but is significant. Previous studies of remining have emphasized the role of physical BMPs in reducing load through a reduction of flow. Chemical BMPs, such as alkaline addition or alkaline redistribution, are unlikely to have much, if any, influence on flow. Therefore, the positive effects are almost certainly due to added alkalinity and neutralization of acid contributed from the calcareous materials.

The BMPs that were predicted to be most effective in terms of iron loadings were special water handling (73.1 percent) and biosolids addition (62.9 percent). Special water handling is primarily a physically effective BMP, whereas, biosolids addition functions geochemically and perhaps physically, through increased plant growth and density which may increase water consumption. Therefore, no common causation trend between these BMPs, in terms of how they functioned to improve iron loadings, was definite. The BMPs that were predicted to be most effective in terms of manganese loadings were alkaline redistribution (92.6 percent) and biosolids application (96.1 percent). The total number of discharges affected by each of these BMPs was low (5 for biosolids and 4 for alkaline redistribution). Therefore, these conclusions are not definitive. As with manganese loadings, the most successful predicted single-use BMPs dealing with aluminum loadings were biosolids application (96.4 percent) and alkaline redistribution (93.3 percent). Again, the number of discharges affected by each of these BMPs was low (<4), and these conclusions are not definitive.

The efficiency predictions of BMPs indicate that most BMPs, if properly employed, will improve contaminant loadings. No BMP was shown to be overall detrimental in terms of increasing contaminant loadings. With further analysis of flow and concentration data, the determination of whether the change in loadings was physical or geochemical is expected to be more definite.

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